00063807

0
627.120977
Daw/Not
63807

Digitized with financial assistance from the
Observer Research Foundation
on 25 April, 2019

NOTES

ON THE

MISSISSIPPI RIVER,

INCLUDING

BRIEF DESCRIPTIONS OF THE METHODS ADOPTED BY THE MISSISSIPPI ENGINEERS

IN ITS SURVEY, DISCHARGE MEASUREMENT, SEDIMENT OBSERVATION, CONSTRUCTION OF LEVEES, BANK PROTECTION, CHANNEL IMPROVEMENT WORKS AND IN DREDGING, ETC.; WITH OPINIONS OF THE MISSISSIPPI RIVER COMMISSION AND OTHERS ON THE EFFECT OF LEVEES, OUTLETS, CUT-OFFS, ETC.

BY

E. F. DAWSON,

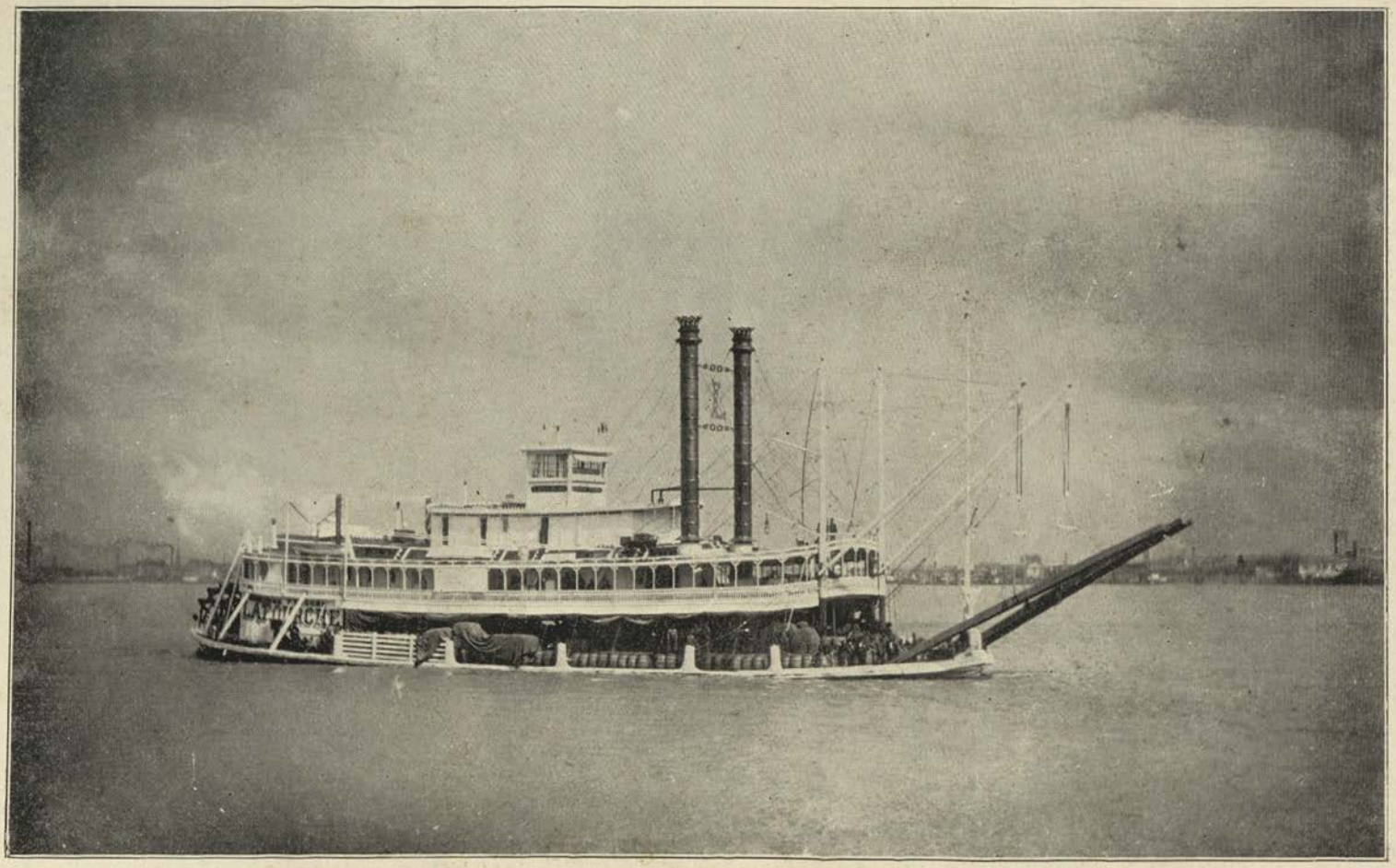
Assoc. M. Inst. C.E., Exe. Engr., Bombay Presidency

Calcutta:

THACKER, SPINK & CO.

1900,

CALCUTTA:
PRINTED BY THACKER, SPINK & CO.



Cargo Steamer on the Mississippi.

PREFACE.

THESE notes were compiled by the writer while on special duty on the Mississippi River for a period of six months under the orders of the Government of Bombay, the object of his deputation being to study the practice of the Mississippi Engineers with a view to recommending the adoption of such of their methods of scientific research and engineering principles as might be suitable to the Indus River. The special points to which attention was directed by the Government of Bombay were as follows :–(*a*) The methods of taking and recording scientific observations of the river regarding velocity, discharge, matter held in suspension, change in bed and water level, alluvion and diluvion and reclamation of land, and the scientific and other instruments used; (*b*) the manner in which the survey of the river is carried out, the maps and charts in use, and the manner of recording changes of levels and currents on them; (*c*) the methods employed in dredging, clearing and blasting snags and removing obstructions generally, and the plant and machinery employed; and a further comprehensive request was added that "any points of interest" connected with the river and its conservation be brought to notice. The writer has endeavoured to note briefly upon nearly all of the above, but it has been impossible in the time available to do justice to some of the subjects taken up, which have been for many years problems for special study, experiment and development by river experts of exceptional ability and experience. Owing however to the courtesy of the United States Officials, generally, to the willing assistance and amount of information given by all district officers and to the special facilities placed at his disposal, he has been able to obtain and bring together what may be called authoritative opinions on many previously disputed points connected with large

alluvial rivers and to describe some of the more important works of the Mississippi River in sufficient detail to fulfil the requirements of these notes. The writer had the privilege of accompanying the Mississippi River Commission on their December 1898 river inspection from St. Louis to the Gulf and of inspecting at different points on the river many works of importance and interest. He would here acknowledge the courtesy shown to him by the Hon. Mr. Meiklejohn, Assistant Secretary of War, by General Wilson, Chief of Engineers, U. S. Army, by General Gillespie, U. S. Engineers, President of the Mississippi River Commission, by the Members of the Commission, and by Colonel Stickney, U. S. Engineers, President of the Missouri River Commission. He is indebted to a great many of the River Engineers for information and assistance, particularly to Mr. Harrod, Member of the Mississippi Commission and Engineer, New Orleans Drainage Works, to Major Handbury, U. S. Engineers, to Mr. Ockerson, Member of the Mississippi Commission and Special Engineer in charge of the Survey of the Mississippi, to Mr. Starling, late Chief Engineer, Mississippi Levee District, to Mr. Richardson, Chief Engineer, Louisiana, to Colonel Chittendan, U. S. Engineers, to Mr. Waters Fox and Mr. Curry, and to Captains Townsend, Newcomer, Jervey, Winslow, District Officers, U. S. Engineers; also especially to Captain Patrick, U. S. Engineers, Secretary of the Mississippi River Commission, and to Mr. Kivas Tully, Assistant Engineer in the Secretary's Office, to both of whom he had to constantly appeal for assistance in some shape or form.

April 20th, 1899.

E. F. DAWSON,

Exe. Engr., Bombay, on special duty.

TABLE OF CONTENTS.

	Page.
PREFACE	i

CHAPTER I.

INTRODUCTORY REMARKS	1
DRAINAGE BASIN—	
The Ohio Basin	3
The Upper Mississippi	3
The Missouri Basin	3
The Arkansas Basin	4
The Red River Basin	4
The Central Valley	4
Sub-Divisions of the Central Valley	4
The Tensas Bottom	5
The Delta	6
CHARACTER OF THE LOWER MISSISSIPPI—	
Cross Section	7
Slope	7
Levees	8
Rainfall	8
Floods	8
High Stage Discharge	10
Low Stage Discharge	10
Oscillation of Stage	10
CONTROL AND ORGANIZATION—	
The Mississippi Commission	11
District Control	12
Composition of the Commission	12
SENATE COMMITTEE OF 1897	13

CHAPTER II.

SURVEY OF THE MISSISSIPPI RIVER—	
Tertiary Triangles	16
Topography	16
Hydrography	17

Page.

SURVEY OF THE MISSISSIPPI RIVER—*(Contd.)*

Locating Soundings 18
Sounding Boat 20
Supplementary Surveys 20
Special Survey 21
Excellent Style of the Mississippi Maps 21
The Ockerson Stenciling Outfit 22
The Ockerson Topographic Mapping Device 22

GAUGES—

Bulletins 26
Highwater Gauges 27
Tide Gauges 27

DISCHARGE MEASUREMENT—

Six-tenths Depth Observations 28
The Current Meter 28
History 28
Rods, Floats and Meters 29
Rod Floats 30
Submerged or Double Floats 30
Double Floats used in 1897 30
Float Run 32
Comparison of Methods 33
Current Meters 33
Present Methods and the Six-tenths Depth Velocity 33
Selection of Gauge Site 34
Taking the Measurements 35
Record of Field Work 36
Field Computation 36
Rating the Current Meter 37
Reduction of Formula 38
Graphic Method of Solution 39
Final Reduction of Discharge Observations 40

SEDIMENT OBSERVATIONS—

Measurement 47
Silt Observations at St. Charles 48
The St. Charles Silt Bottle 49
Obtaining Samples of Water... 51
Method of Computation 51

CHAPTER III.

EROSION OF BANKS—

Definitions, Caving, Slough and Slump 53

Page.

EROSION OF BANKS, (*contd.*)—
Kinds of Caving 54
Lateral Oscillation of the River 55
Extent of Erosion 56
Estimate of Erosion 58
Conclusions of Analysis of Maps and Diagram 59
Effect of Slope on Erosion 60
Definite Conclusions by Mr. Ockerson 61
Further Conclusions by the Writer 62
The Mississippi Commission's Description of Caving 64

CHAPTER IV.

LEVEES OR PROTECTIVE EMBANKMENTS—
History 66
District Control 66
Summary of above 67
Levee Requirements 68
Materials of which Levees are composed 68
Precautions in Construction 69
Cross Section 70
Grade of Levee Line 71
Distribution of Grades 73
Muck Ditch 74
Letting Water against New Levees 75
Care of Levees in the Flood Season 75
Sloughing of Levees 76
Treatment of Subsidence in Levees... 77
Capping 78
Protection of Slopes 79
Crevasses 80
The "Creole Plan" of closing crevasses 80

LESSONS OF THE 1897 FLOOD—
Mississippi Commission Committee's Report on Final Grade 85

LEVEE CONSTRUCTION IN 1898—
Mr. Starling on above in 1898 89
Approved Cross Section for Levees 90
Specifications for construction of Levees 90

EFFECTS OF LEVEES ON THE RIVER CHANNEL—
Recorded opinions of the Mississippi Commission 91
General Comstock on the question whether building Levees along a River causes its bed to rise 93
Captain Townsend, Corps of Engineers' opinion on this question ... 95

Page.

EFFECTS OF LEVEES ON THE RIVER CHANNEL, (*contd.*)—
Mr. Harrod's Observations 96
Mr. Starling's views 97
Results of special survey made by Mr. Ockerson 98
Final conclusions by the Writer 99

CHAPTER V.

FLOODS AND PREDICTION OF GAUGE HEIGHTS—
Forecasting Floods and Flood Heights 104
Prediction of Floods 107
RELATION BETWEEN STAGE OF RIVER AND EROSION OR FILL OF THE BED ... 111
EFFECTS OF "CUT-OFFS" ON RIVER CHANNELS—
Mr. Starling on "cut-offs" 113
"Cut-offs" proposed by Mr. Pharr in 1897 114
General opinion 114
Prevention of "cut-offs" 114
Cut-offs on the Indus 115
OUTLETS—
Captain Powell's investigation into effects of outlets 116
Atchafalaya mouth 118
Colonel Suter's investigations 119
Mr. Starling on this question 119
Opinion of the Mississippi Commission 120
Mississippi Commission in 1893 121

CHAPTER VI.

INTRODUCTORY REMARKS ON RIVER IMPROVEMENTS 123
BANK REVETMENT—
Effect on Channels 125
Mr. Coppee on Bank Revetments 126
Object of Revetment 126
CONTINUOUS REVETMENT—
Change in method of construction in 1881 129
Early decisions of the Mississippi River Commission 130
The Woven Mattress 131
Omission of Mattress above water level 134
Standard continuous Revetment, 1890 134
Grading 140
Bank Revetment, 1893 140
Fascine Mattress Revetment 140
Advantages of the Fascine type 145
Expressed conclusions of the Mississippi River Commission in 1896 ... 146

Page.

CONTINUOUS REVETMENT, (*contd.*)—
Present practice 147
DISCONTINUOUS OR DETACHED REVETMENT—
Submerged Spur Dikes 149
Details of Dike Construction 150
Details of Crib Construction 151
Statement of cost of Greenville Dike No. 2, 1889 152
New Orleans Spur Dikes, 1890 153
Mr. Coppee's Concluding Remarks 154
Work of 1894 155
Work of 1896 155
Giles Bend Spurs, 1897 156
Success of Spur Dikes on the Lower Reaches 158
Opinion of Mississippi River Commission on general use of Spur Dikes in Upper Reaches of the River 158
Work of 1898 159
Latest New Orleans Work 159
BANK HEADS, MISSOURI RIVER—
Details of Construction 161
Colonel Stickney's Theory on use of Bank Heads 163
Bank Heads, Missouri River, 1898... 165

CHAPTER VII.

CHANNEL CONTRACTION WORKS—
Channel Contraction Works 167
Mississippi River between the Ohio and Missouri Rivers 167
Definition of Hurdle 167
Closing Sloughs 169
Jet Dredge 170
Portable Jetties 170
Suitability of this length of River for Channel Contraction Works ... 171
Work of 1898 172
Temporary Channel Improvement, 1898 174
Portable Jetties 174
Early types of Hurdles 175
Materials used and cost of hurdle construction 176
Plant and Working Gang 179
MISSOURI RIVER IMPROVEMENTS 180

SILL DAMS—
Construction of Sill Dams 182

Page.

CHAPTER VIII.

SUBAQUEOUS ROCK EXCAVATION—
Method of Operation 185
Drilling 186
ROCK BLASTING, ROCK ISLAND RAPIDS—
Drill Boats 187
Improvements Advisable 188
Cost of Drill Boat 188
Drilling Operations 189
Explosives 189
General 190
Plant 190
AETNA DYNAMITE AND BLASTING BY ELECTRICITY—
Safety 191
Brands and Grades 191
General Directions 191
Materials 192
Blasting under Water 192
Freezing and Thawing 193
Blasting by Electricity 193
Directions 193
Electrical Exploder 194
Electrical Blasting Machines 194
Leading Wire 195
Connecting Wire 195
Cost of Outfit 195
SNAG BOATS—
Snag Boat Wichita 196
Wabash River Snag Boats 197
Twin Bow 197

CHAPTER IX.

DREDGERS AND DREDGING—
Mr. Ockerson on this subject 198
Sand Bars as obstructions to Navigation... 200
Appointment of a Committee to study and report on a Project for Dredging 201
Experimental Dredge Alpha 202
Dredge Beta 203
Dredge Gamma 206
Dredge Delta 210
Dredges Epsilon and Zeta 213

Page.

DREDGERS AND DREDGING, (*contd.*)—
Major Handbury's Dredge No. 2 218
Major Handbury's Dredges Nos. 3 & 4 219
Improvements made in Major Handbury's Nos. 3 & 4 ... 220
General 221
Principal features of some of the Dredge Boats operating on the Mississippi River below St. Louis 223
HYDRAULIC PILES 226
DREDGE CAPACITY TESTS MADE IN 1898—
Gamma 228
Delta 229
Epsilon 229
Zeta 229
GENERAL REMARKS AND COMPARISON OF DREDGES—
Comparison of Efficiency 231
Variety of Design 233
PRELIMINARY SPECIFICATION FOR LARGE DREDGE INDUS 236
SELF-PROPELLING DREDGERS—
Dredge Ram 239
Review 242
SMALL DREDGE INDUS—
Specification for small Dredge Indus 244

LIST OF PLATES.

		Page.
Cargo Steamer on the Mississippi	Facing Page	1
Map of the United States showing the Mississippi River and its tributaries	Facing Page	1
Map showing Drainage Basin of the Mississippi River ...	„ „	4
Map of Lower Mississippi River	„ „	7
River Steamers, New Orleans	„ „	11
View of River Front, New Orleans	„ „	15
Reduced Sample Sheet of Survey of the River	„ „	16
Map of Cherokee Crossing	„ „	21
Specimens of printed Signs and Letters for Topographical Maps	„ „	24
View of Memphis	„ „	27
View of New Orleans Harbour	„ „	28
Plan of Discharge Station showing Position of Stations, Range Signals, &c.	„ „	47
Plan of the St. Charles Silt Bottle	„ „	50
View of Caving Bank at Kemp's Bend	„ „	53
Diagram showing extent of Caving	„ „	60
Raising a Levee with Scrapers	„ „	66
View of Crevasse	„ „	80
View of Crevasse closed by Sand-bags	„ „	81
Typical Cross-section for Levees	„ „	90
Sketch of River Mississippi showing Inlets and Water Slopes	„ „	96
Levee Scene in Flood Season	„ „	101
Diagram of Flood Prediction Curves	„ „	107
Map of River showing outlets near the Sea " ...	„ „	116
View of Head of South Pass	„ „	117
View of Mouth of South Pass near Gulf	„ „	121
View of Caving Bank	„ „	125
Type of Mattress used in lower reaches of the river ...	„ „	129
Collection of materials for Bank Revetment	„ „	134
Plan showing system of mooring barges during construction	„ „	136
Views of Mattress Plant (four)	„ „	140
Sketch showing construction of Mattress Head	„ „	141
River view of New Orleans Front	„ „	149
Sketch Plan and Sections, New Orleans Dikes	„ „	154
Plan and Section of Bank Head	„ „	160

			Page.
View of Bank Head, Chamois Bend	Facing Page.		165
View of Bank Head under construction	,,	,,	166
View of Bank Head practically completed	,,	,,	166
Hurdle Dike on the Mississippi	,,	,,	167
Mattress Revetment between Cairo and St. Louis	,,	,,	169
Sketch of Portable Jetties	,,	,,	171
Sketch map of Hurdles built in vicinity of commerce ...	,,	,,	174
Sketch plan in the vicinity of St. Genevieve	,,	,,	174
Sketch of earliest type of Hurdle	,,	,,	176
Sketches showing Development of Hurdle	,,	,,	176
Plate of Types of Hurdles	,,	,,	176
Missouri River Dike, system of bracing	,,	,,	180
Views of Nebraska City Dikes (two)	,,	,,	181
View of the Atchafalaya River	,,	,,	182
Dike Work, Missouri River (Plates 1 to 4)	,,	,,	184
Revetment Work, Missouri River (Plates 5 to 8)			
Plan of Drill Boat	,,	,,	188
The "Wichita" Snag Boat	,,	,,	196
Capacity Test, Dredge Epsilon	,,	,,	199
General View, Dredge Gamma	,,	,,	200
Main Pump, Dredge Gamma	,,	,,	206
Interior View, Dredge Gamma	,,	,,	208
View of Dredge in operation	,,	,,	210
Machinery, Dredge Zeta	,,	,,	210
Dredge Delta and Discharge Pipes	,,	,,	212
General View, Dredge Epsilon	,,	,,	213
Plan and Elevation, Dredge Epsilon	,,	,,	216
Suction Heads, Epsilon and Zeta	,,	,,	217
Jet Pump and Engine, Dredge Epsilon	,,	,,	218
Delivery Pipe, Epsilon and Zeta	,,	,,	219
The Edwards Pump	,,	,,	220
Details of Hydraulic Pile	,,	,,	226
Dredging Steamer Ram	,,	,,	239
Plan and Elevation, do. do.	,,	,,	240
Profile of High and Low water between Cairo, Ill., and Fort Jackson	,,	,,	284
Part of Dredge Fleet in Winter Quarters	,,	,,	285
Steamer Mississippi	,,	,,	336
Port Engine for Main Pump, Dredge Epsilon ...	,,	,,	336

APPENDICES

		Page.
A.	Instructions for Gauging Parties	247
B.	Captain Patrick's specifications for Levee construction ...	277
C.	Longitudinal Section of High and Low Waters, Mississippi River ...	284
D.	Specification for Major Handbury's Dredges Nos. 3 and 4 ...	285
E.	Specification for Steel Hull Tender	313
F.	Log of the U. S. Steamer "Mississippi" on the Commission's Inspection Trip, 1898	331

ACCOMPANIMENTS.—(Handed over to the Government of Bombay.)

Copies of Annual Reports of the Chief of Engineers.

U. S. Army from 1879 to 1897 inclusive, in all 84 vols.

Report of the Mississippi Commission for 1881, 1 volume.

Current Meter Observations of the Mississippi River by Lieut.-Col. Alexander MacKenzie, U. S. Engineer, 1 volume.

Report on Floods of the Mississippi, prepared under the direction of Mr. Willis N. Moore.

Humphreys and Abbot on the Mississippi River, 1 volume.

Maps, Mississippi River 1 : 20,000 sheets, Nos. 79 to 83,

Maps, Mississippi River, bound in board, 1 inch to 2 miles, compiled by Mr. Ockerson.

Maps of Mississippi River, scale 1 inch to 1 mile, from Cairo to head of Passes, 32 sheets ; and sheets 101 to 120 above Cairo, all bound in leather.

Blue prints showing Caving between Cairo and Donaldsonville.

Blue prints of Fascine Mattress.

" " Missouri River Bank Head.

" " Major Handbury's Tender.

" " Mississippi Commission's small Tender.

" " Hydraulic Piles.

" " Drill Boat.

" " 3 sheets Dredge Ram.

" " Hydrograph Mississippi River.

Blank Form of " " "

MAP OF THE UNITED STATES SHEWING THE MISSISSIPPI RIVER AND ITS TRIBUTARIES.

Statute Miles
Mississippi River
Red River
Yellow Stone
Missouri
Ohio River
Arkansas
White River
Prince Albert
Battleford
Calgary
Medicine Hat
Qu'Appelle
Swift Current
Moosejaw
Portage
Winnipeg
Port Arthur
Duluth
Minneapolis
St Paul
Green Bay
La Crosse
Dubuque
Rock Island
Davenport
Chicago
Detroit
Toledo
Cleveland
Buffalo
Rochester
Albany
Boston
Montreal
Quebec
Ottawa
Kingston
Toronto
Hamilton
Niagara
Sault Ste Marie
Parry Sound
Owen Sound
Saugeen
Collingwood
Orillia
Peterboro
Belleville
Brockville
Cornwall
Prescott
Gananoque
Arthur Point
Charlottetown
Halifax
Yarmouth
Bathurst
Moncton
Fredericton
St John
Portland
Augusta
Concord
Burlington
Rutland
Bellows Falls
Keene
Nashua
Manchester
Lowell
Lawrence
Haverhill
Salem
Boston
Providence
Newport
New Haven
Hartford
Springfield
Worcester
Albany
Troy
Schenectady
Utica
Syracuse
Rochester
Buffalo
Niagara
Scranton
Wilkesbarre
Reading
Harrisburg
Philadelphia
Trenton
Camden
Atlantic City
Baltimore
Washington
Annapolis
Fredericksburg
Richmond
Petersburg
Norfolk
Portsmouth
Raleigh
Wilmington
Charlotte
Columbia
Augusta
Charleston
Savannah
Jacksonville
Tallahassee
Pensacola
Mobile
Montgomery
Vicksburg
Meridian
Jackson
Natchez
New Orleans
Port Eads
Shreveport
Monroe
Alexandria
Galveston
Houston
Austin
San Antonio
Corpus Christi
Brownsville
Matamoras
Laredo
Eagle Pass
Del Rio
Fort Worth
Abilene
Waco
Dallas
Sherman
Denison
Paris
Texarkana
Little Rock
Fort Smith
Hot Springs
Memphis
Nashville
Chattanooga
Knoxville
Louisville
Cincinnati
Indianapolis
Terre Haute
Evansville
Springfield
Jefferson City
St Louis
Hannibal
Kansas City
Leavenworth
Atchison
St Joseph
Omaha
Council Bluffs
Sioux City
Fort Dodge
Des Moines
Keokuk
Burlington
Quincy
Peoria
Bloomington
Decatur
Lafayette
Terre Haute
Indianapolis
Springfield
Columbus
Dayton
Zanesville
Wheeling
Pittsburgh
Erie
Cleveland
Akron
Canton
Youngstown
Meadville
Oil City
Williamsport
Harrisburg
Lancaster
Reading
Allentown
Easton
Scranton
Binghamton
Elmira
Corning
Rochester
Syracuse
Oswego
Watertown
Ogdensburg
Plattsburg
Burlington
Montpelier
Concord
Manchester
Nashua

NOTES

ON THE

MISSISSIPPI RIVER.

CHAPTER I.

Introductory Remarks—Drainage Basin—Character of the Lower Mississippi —Control and Organization—Senate Committee of 1897.

INTRODUCTORY REMARKS.

SINCE the publication of Humphreys and Abbot's book on the Mississippi River in 1861, a great many investigations in different directions have been undertaken by the Mississippi Engineers. The river has been systematically surveyed, special study has been made of its discharges, movement of bars, effect of training works, methods of bank protection, levee construction, &c.; and upon all of these subjects reports have been made by the Engineers to the Commission, or to the Chief of Engineers, U. S. Army.

Many of these reports have been compiled in the Annual Reports of the Chief of Engineers. In addition, several specially valuable notes or papers have been written and separately published, amongst which may be particularly mentioned "Wheeler on Discharges," "Copee on Bank Revetment," "Ockerson on Caving Banks," "Starling on Discharge of the Mississippi River," "Starling on Floods of the Mississippi and its Levee System," "Corthell on the Mississippi Jetties," and "Ockerson on Dredging."

The writer does not propose in his notes on the Mississippi River to give a digest of what has been written up to the present. That would be too great an undertaking. But he purposes noting particularly on special features of organization, survey, discharge measurement, methods of construction, and results of experiments, which appear to him during his inspection of the river as likely to be helpful to the Engineers of the Indus River.

A brief description of the Mississippi River basin will assist in the understanding of what will be written, and will therefore be given

first. It is compiled from extracts of the Weather Bureau Report of 1897 on the Floods of the Mississippi, prepared under the direction of Mr. Willis Moore, and from printed reports of the Mississippi Commission.

Through a faulty nomenclature, the Mississippi River is only 2,485 miles in length. The Missouri is really the upper prolongation of the main river, the Upper Mississippi being one of the less important tributaries. From the source of the Missouri to the mouth of the Mississippi is 4,190 miles, constituting probably the longest water-way in the world. It is navigable at certain seasons of the year for a distance of 3,950 miles.

DRAINAGE BASIN.

THE drainage basin of the Mississippi includes 1,240,050 square miles of territory, or over 40 per cent. of the total area of the United States, exclusive of Alaska. It embraces six great natural divisions: the basins of the Ohio, Upper Mississippi, Missouri, Arkansas and Red Rivers together with the basin of the river from the mouth of the Missouri to the Gulf called the Central Valley. The boundaries of these sub-divisions are shown on map II.

In percentages of the whole, the basins have areas as follows :— Ohio ·16, Upper Mississippi ·13, Missouri ·43, Arkansas ·15, Red ·07, Central Valley ·06.

The Ohio Basin.

The Ohio River is 960 odd miles in length, and may be said to drain the whole of the Western Alleghany slopes, as well as a considerable tract of land south of the Great Lakes. Its fall or grade per mile is about ·44 feet. Its flood section at Paducah, 45 miles above the mouth, varies from 150,000 to 200,000 square feet. The maximum and minimum discharges recorded for that station are 1,233,000 and 42,000 cubic feet per second respectively.

The Upper Mississippi.

The Upper Mississippi rises in Lake Itasca, west of Lake Superior, and meanders through a winding course of 500 odd miles before it becomes navigable. The head of navigation is at the falls of St. Anthony, 690 miles above the mouth of the Missouri, or 1,970 miles from the mouth of the Mississippi. The fall in the navigable length averages ·59 feet per mile. The cross-section of the river at its junction with the Missouri is about 100,000 square feet. The maximum and minimum discharges recorded at Grafton, Ill., 42 miles above St. Louis, are 337,000 and 25,000 cubic feet per second respectively.

The Missouri Basin.

The Missouri Basin is the largest of the six sub-divisions, but it is also the driest. The variety of its topographical features is unsurpassed, comprising wild mountainous districts of the Rockies, barren treeless tracts at the foot of the hills, which change to fertile plains gently sloping towards the Mississippi Basin. The Missouri is navigable at certain seasons for a

length of 2,670 miles. Its fall is ·97 feet per mile, and its cross-section at the mouth is roughly 75,000 square feet. At Kansas City, Mo., 386 miles above the mouth, the measured maximum and minimum discharges are given as 370,000 and 19,000 cubic feet per second respectively, while at St. Charles, 25 miles from the mouth, a flood of 600,000 cubic feet has been measured. But it usually does not exceed 300,000 cubic feet per second.

The Arkansas Basin.

The Basin of the Arkansas River is similar in its variety of topography and dryness to the Missouri. It is navigable for about 650 miles, and in this length has a fall of about ·62 feet per mile. Its cross-section, at high water, is about 50,000 square feet. Its discharge varies from 460,000 at high water to 4,000 cubic feet per second at low water.

Red River Basin.

The Red River Basin is very similar to the Arkansas though smaller in extent. It discharges into the delta of the Mississippi. At certain stages, though, the Red discharges part of its water direct into the Gulf through the Atchafalaya Bayou, and can then hardly be classed as a true tributary of the Mississippi. Its maximum discharge is 228,000, and minimum 4,000 cubic feet per second.

Central Valley.

The Central Valley includes the small basins which are drained by direct tributaries of the Mississippi south of the Missouri. Together they form a strip of country nowhere exceeding 200 miles in width, and terminating in the delta. The only important streams are the St. Francis and the Yazoo, draining the two basins of the same names. Though the area included in the valley is small, the annual precipitation over it is heavy and the watercourses are short ; consequently it contributes considerably to the discharge of the Mississippi, being exceeded only by that of the Ohio. Flood discharges of 373,000 and 101,000 cubic feet per second respectively have been measured on the St. Francis and Yazoo, and in 1897 the flow down the basin of the St. Francis was as much as 580,000 cubic feet per second. Of this, however, a considerable portion was overflow from the Mississippi.

Sub-divisions of the Central Valley.

Mr. Moore divides the Central Valley into six districts. The first shown as A on the map is the country extending from the mouth of the Missouri to Cape Girardeau, Mo. on the right bank, and to the mouth of the Ohio on

DRAINAGE BASIN OF THE MISSISSIPPI RIVER.

Map XII

the left bank. The whole region is hilly on the right bank, and contains no land liable to inundation. On the left bank what is known as the American bottom between the mouth of the Missouri and the Kaskashia is liable to inundation in high floods.

The next sub-division, marked as B, is the St. Francis Basin, extending from Cape Girardeau to Helena, Arkansas, on the right bank. It has an area of 10,500 square miles, one-third of which is hilly and two-thirds is low swampy land, known as the St. Francis bottom. The bottom is nearly level, but slopes towards the west, away from the Mississippi with an average grade of six inches per mile, and from north to south about nine inches per mile. From Point Pleasant south for 125 miles a levee borders the river.

The third sub-division lies between Cairo, Ill., and Memphis on the left bank, and consists of hilly country with bluffs running close to the river. The greater part of it is drained by the Obion and Hatchee Rivers. Of the whole area of 10,000 square miles only about 600 is liable to inundation.

The fourth sub-division marked D is the Yazoo bottom, extending from below Memphis to Vicksburg on the left bank. Like the St. Francis it slopes away from the Mississippi and descends to the south. It is a heavily timbered alluvial plain 180 miles in length by 70 miles in width at its broadest part. The Yazoo, which flows along the eastern boundary of the bottom, drains about 14,000 square miles. The bottom liable to overflow is about 6,650 square miles in area.

The fifth sub-division is on the left bank between Vicksburg and Baton Rouge. This area is hilly, and out of a total of 7,250 square miles only 400 odd are liable to overflow.

The last sub-division is the Delta, namely, all that alluvial region which stretches southward from the Red River. It is marked F on the map.

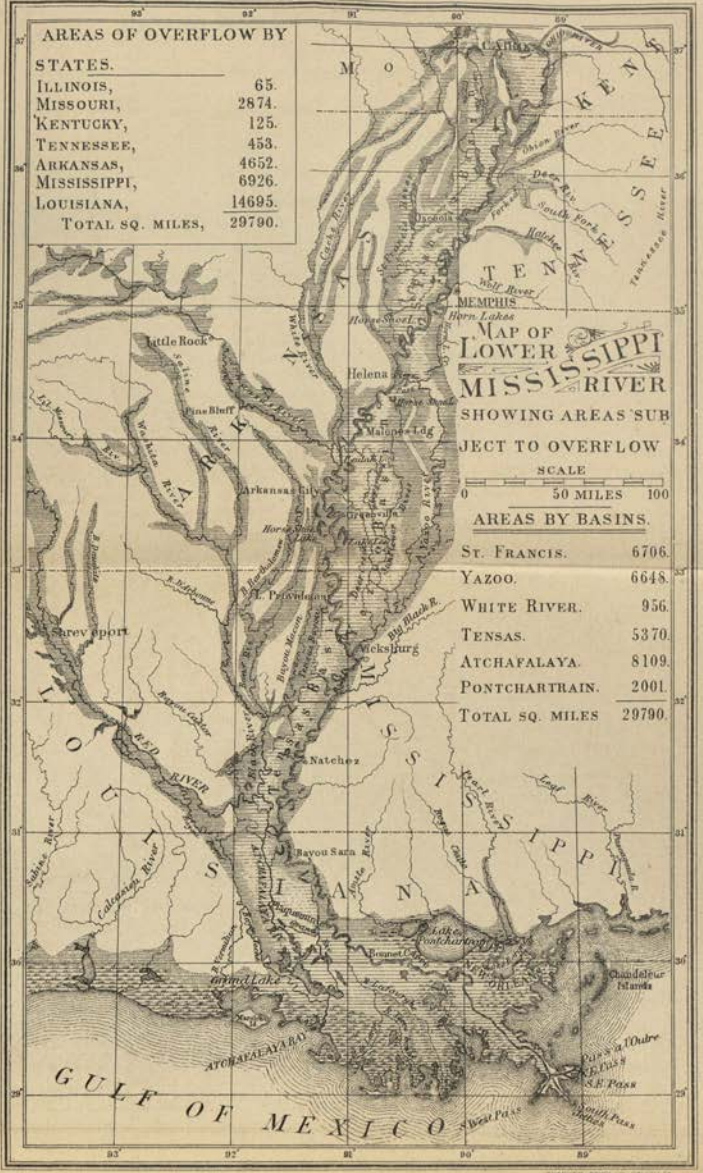
The Tensas Bottom.

The Tensas bottom, extending from the southern border of the St. Francis to the Red River, about 5,000 miles in extent, is similar to the St. Francis and Yazoo bottoms. It is chiefly drained by Bayou Tensas, a feeder of the Black, the most important tributary of the Red River. Its area is included in the Arkansas and Red River basins, and not in that of the Central Valley.

The Delta.

The Delta is a low swampy region, 12,000 square miles in extent, intersected by countless bayous. About 4,000 square miles are a sea marsh, and 10,000 out of the 12,000 are liable to to be overflowed. The main drain of the Delta is Bayou Atchafalaya, which leaves the Red River above its mouth and, flowing south through Grand Lake, reaches the sea at Atchafalaya Bay. Bayou Plaquemine formerly left the Mississippi 20 miles below Baton Rouge and connected with the Atchafalaya, but this Bayou was closed by the Mississippi levee board. Lower down, at 80 miles above New Orleans, the second great drain of the Delta, known as Bayou Lafourche, leaves the Mississippi at Donaldsonville. This flows south and south-east and discharges into the Gulf between the mouths of the Atchafalaya and the Mississippi.

The Mississippi itself continues between its own banks through the Delta as a well-defined and tolerably stable channel, till it reaches what is known as the "Passes." There it divides into three distinct channels, known respectively as the south, south-east, and south-west; the middle or south pass being the navigable channel, which has been deepened and been kept open by the construction of jetties at its mouth and by dikes throughout its length and at its entrance.


AREAS OF OVERFLOW BY STATES.
ILLINOIS, 65.
MISSOURI, 2874.
KENTUCKY, 125.
TENNESSEE, 453.
ARKANSAS, 4652.
MISSISSIPPI, 6926.
LOUISIANA, 14695.
TOTAL SQ. MILES, 29790.
MAP OF LOWER MISSISSIPPI RIVER
SHOWING AREAS SUBJECT TO OVERFLOW
SCALE
0 50 MILES 100
AREAS BY BASINS.
ST. FRANCIS. 6706.
YAZOO. 6648.
WHITE RIVER. 956.
TENSAS. 5370.
ATCHAFALAYA. 8109.
PONTCHARTRAIN. 2001.
TOTAL SQ. MILES 29790.
CAIRO
MEMPHIS
Little Rock
Helena
Pine Bluff
Arkansas City
Greenville
Vicksburg
Natchez
Bayou Sara
Shreveport
Grand Lake
GULF OF MEXICO
MISSOURI
KENTUCKY
TENNESSEE
ARKANSAS
LOUISIANA
MISSISSIPPI

M. & P. No. II

CHARACTER OF THE LOWER MISSISSIPPI.

From the mouth of the Missouri to the Gulf of Mexico, a distance by water of 1,280 miles, the river is designated as the Lower Mississippi. For most of this distance its course is through an alluvial plain Mr. Moore states that the alluvion rarely exceeds 40 feet in depth, and is underlaid by a hard blue clay. The extent of this alluvial region is shown on map III. The immediate banks of the river are higher than the land further back, which for the most part is below high-water level. The slope of the adjoining land is about 7 feet per mile in the first mile, diminishing until the swamp is reached a few miles back from the face of the river.

The direct distance from the head of the plain to the mouth is less than 600 miles, but by the tortuous river channel it exceeds 1,100 miles.

Humphreys and Abbot state it carries sediment to the extent of $\frac{1}{1500}$th part of its weight by water.

It is a turbulent stream, eating away its banks in the bends, building and destroying islands and bars in its channel, and occasionally making great changes at cut offs of large bends, which temporarily alter the length of river in which they occur by several miles.

Cross Section.

In its course through the alluvial plain the Mississippi decreases in width and increases in depth, while its flood cross section changes but slightly. Humphreys and Abbot give the cross section from Cairo to the Passes as 191,000 to 200,000 square feet; and widths at Cairo to Arkansas 4,470 feet, thence decreasing to the Passes to 2,470 feet, with maximum depth of 87 feet at Cairo, increasing to 130 feet at the Passes. Later surveys show still more marked greater depths in the lower reaches.

Slope.

The slope of the water surface of average stages of the river is given by Mr. Moore, by reduction from gauge readings, as follows :—

From St. Louis to Cairo,	191 miles,	·528 feet per mile.	
„ Cairo to Memphis,	230 „	·403 „ „ „	
„ Memphis to Vicksburg,	369 „	·353 „ „ „	
„ Vicksburg to Carrollton,	358 „	·173 „ „ „	
„ Carrollton to the Gulf the slope is very slight.			

From the Chief of Engineers' Report for 1897, which gives the elevations of the maximum stage of the 1897 flood at different gauge stations, the fall of surface, or slope per mile of top water at different gauge stations, is as follows :—

From Cairo to Memphis,	·438	feet per mile.
„ Memphis to Vicksburg,	·334	„ „ „
„ Vicksburg to Carrollton,	·219	„ „ „
„ Carrollton to Fort Jackson,	·164	„ „ „

Levees.

From Fort Jackson, twenty miles above the head of the Passes, to Baton Rouge the river is leveed, or embanked, on both sides. Then on the east, or left bank, there is no levee till the Yazoo bottom is reached. On the west, the levee continues to the Red River, thence after a gap of about thirty miles it extends to a point twenty-five miles below the Arkansas River, and is again continued from above the Arkansas to Helena. Further north the St. Francis levees begin and extend to Point Pleasant, Mo.

Rainfall.

The average annual rainfall or precipitation on the various watersheds is given by Mr. Moore as follows :—

Ohio Basin,	44·2 inches.	Arkansas Basin,	29·6 inches.
Upper Mississippi,	31·9 „	Red „	39·1 „
Missouri Basin,	19·4 „	Central Valley,	51·4 „

Mr. Moore estimates the total downfall of water on each basin and then he practically assumes the ratio of run-off of each though based upon figures given by Humphreys and Abbot, and calculates the total annual discharge. Proceeding in this way he arrives at the run-off, in billion cubic yards, of each basin as follows :—

Ohio	Basin 230 b.c. yds.	Arkansas	Basin 74 b.c. yds.
Missouri	„ 132 „	Red	„ 67 „
Upper Mississippi	„ 125 „	Central Valley	„ 167 „

The total for the Mississippi above the Red River is 718 b.c. yards, or including bayous he puts the total annual discharge of the whole Mississippi River at 785,000,000,000 cubic yards, nearly exactly one-fourth of the precipitation over the whole drainage area.

Floods.

Though it is conceivable that a flood might occur in the Lower Mississippi from heavy precipitation over any of the great contributory basins, the great source of

floods is the Ohio. The heaviest rains of spring fall upon the steep slopes from the Alleghanies at a time when the normal rise of the Lower Mississippi brings the river almost to the danger line from Cairo to the Gulf.

The heavy rainfall over the great swamp region of the Central Valley is also an important factor in producing floods, and the next in importance is the Upper Mississippi, which, though not capable itself of producing a flood, can discharge a volume of water sufficient to prolong the high water and increase the overflow caused by the Ohio.

Mr. Starling, in his paper on Floods of the Mississippi, says: "The Ohio and its tributaries constitute a system by themselves." He divides the tributaries of the Mississippi into the "Eastern and Western systems. To the former belong the Ohio and its affluents alone; to the latter the Upper Mississippi, the Missouri, and usually the St. Francis, White, and Arkansas. So far as is known all these streams have never been in extreme flood at the same time. Such an ominous conjunction would produce a discharge of more than 3,000,000 cubic feet per second, which would be almost twice as great as has ever been observed. But it has often happened that a great flood from the Ohio has met at Cairo a moderate freshet from the Western streams, or that a May or June rise from the Upper Mississippi and Missouri has encountered the crest of a late freshet in the Ohio. In either of these cases may and do occur floods in the lower river by the powerful and decisive aid of the Ozark streams. In fact, it is quite possible for a very great flood in either the Eastern or Western system, combined with merely an average stage in the other, to produce very high water below the mouth of the Arkansas."

Speaking of the great flood of 1897, he says that "of the 1,570,000 cubic feet per second, which passed Cairo at the time of maximum stage, 1,200,000 or 76 per cent. came from the Ohio. The discharge was increased below Cairo by the tributaries, by about 200,000 cubic feet per second, bringing the total of the river up to 1,750,000. Though the Upper Mississippi and Missouri were not especially instrumental in bringing about the highest stage at Cairo, they were responsible for its prolongation. As the Ohio slackened, they increased their supply, until it amounted to nearly half of the whole."

High-stage discharge.

To obtain the correct aggregate maximum discharge of the basin of the Mississippi, it is necessary to combine the discharges of the Atchafalaya, which serves as an outlet to the sea for overflow of the Red and Mississippi Rivers, and of the Mississippi at Red River Landing. The maximum discharge recorded at Red River Landing is 1,595,000 cubic feet per second, observed in 1882, in which year that of the Atchafalaya was 280,613 cubic feet per second. But a closer examination of the high discharges of the two shows that the maximum combination is given on May the 7th, 1890, when the Red River Landing discharge was 1,453,000, and the Atchafalaya was 472,755 cubic feet per second (latter obtained by interpolation from discharges of May 6th and 8th) giving a total of 1,925,755 cubic feet per second as the maximum measured outflow from the Mississippi Basin.

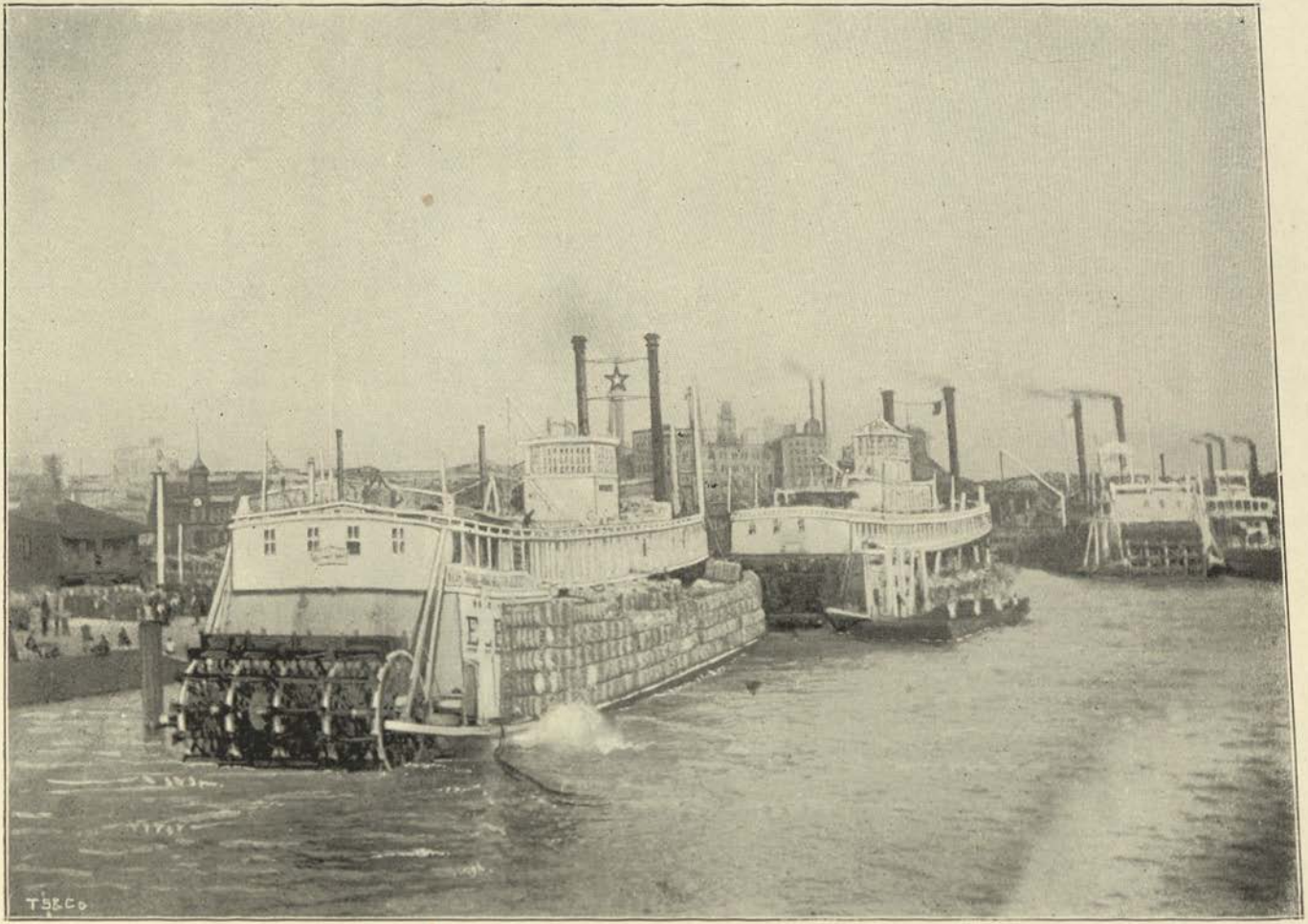
Low-stage Discharges.

The least discharges recorded by the Mississippi Commission are as follows: At Cairo, 114,000 cubic feet per second in 1891; at Columbus, twenty-one miles below Cairo, 71,000 cubic feet per second; at Old Town Bend, 325 miles below Cairo, 77,000 cubic feet per second; and at Red River Landing, 765 miles below Cairo, 94,000 cubic feet per second, all in 1897. The discharges of the Mississippi River may thus be said to vary from 94,000 in low water to 1,925,000 cubic feet per second in high water.

Oscillation of Stage.

The oscillation of the stage or water surface of the river is over fifty feet at Cairo, Helena, White River, Vicksburg, and Natches, the latter being 700 miles below Cairo. At Baton Rouge, 835 miles below Cairo, the oscillation is still forty feet odd; thence it quickly decreases to less than twenty feet at Carollton near New Orleans, and from that point gradually lessens to only a few feet at Fort Jackson. Beyond this, it is little more than that due to tidal influence.

The average tide at Port Eads is only about 15 inches daily. Spring tides rarely exceed 20 inches in height.



River Steamers, New Orleans.

CONTROL AND ORGANIZATION.

From Port Eads to the head of the Passes the river works are in charge of an officer of the Corps of U.S. Engineers, directly responsible to the Chief of Engineers, U.S. Army. From the head of the Passes to Cairo, a length of 1,060 miles, the expenditure of appropriations granted by Congress is under the control of the Mississippi Commission, who are responsible to the Chief of Engineers for the conservation of this length of the river, known as the Lower Mississippi From Cairo to the mouth of the Missouri River constitutes a separate charge held by an officer of the U.S. Corps, under the Chief of Engineers, the present incumbent, Major Handbury, being also a member of the Mississippi and of the Missouri Commissions. The Missouri is managed by a separate commission. The other tributaries are held as separate districts by officers of the Corps of Engineers directly under the Chief of Engineers.

The Mississippi River Commission was organized in 1879, since which date, under their supervision, a survey of the river, scale 1 to 10,000, has been made from the head of the Passes to Cairo and thence up nearly to St. Paul, Minnesota.

The Mississippi Commission.

In addition to general administration of funds, the Commission have given special attention to discharge and other observations, taken with the view of obtaining physical data regarding the river. They have expended very large sums on different descriptions of bank revetment, and are still investigating the question of protection of caving banks in the hope that some method may be devised for accomplishing this purpose, which will be within practical limits of expense.

The final object of the expenditure and their investigations is the improvement of the low water channels of the river and the protection of the country from flood. Where formerly the depths over bars was five feet, or even less, the channels at low water have now a minimum depth of eight feet. It must be admitted however that, so far as the writer could learn, the greater part of the progress made of late years is due to the successful working of the hydraulic dredges, and but little, especially in the lower reaches of the river, to

dike or hurdle work of any description. In the upper reaches of the river above Cairò there is no doubt though that the hurdle work so extensively carried out there has given good results.

District Control.

The length of river under the control of the Commission is divided into four districts each held by an officer of the U. S. Corps, with civil experts as assistants. The expenditure on levees of funds allotted by Congress is under the control of these Officers, but large sums are also spent upon the levee system by the local States concerned. The latter are controlled by the State Engineers. It will thus be seen that there is a sort of dual control of the levee system.

The Commission are practically the advisers both of Congress and of the local States, though they have no control over the expenditure of the latter. It is, however, said that all concerned work together most harmoniously for the common good. As far as answers to questions on such matters could be obtained, the writer gathered that it is generally admitted that complete control by the central government of all expenditure on levees would be preferable, now that it is recognized that the maintenance of the levee system should be considered as a whole and not in independent parts.

Composition of the Commission.

The Commission consists of three officers of U. S. Corps of Engineers, two Civil Engineers, one Officer Coast Survey, and one representative of the legal profession, with an officer of the Corps of Engineers as Secretary. The office of the President of the Commission is in New York, but that of the Secretary is in St. Louis. In addition to his Commission duties the Secretary has the management of discharge observations and dredging, as well as the direction of the survey operations. The President of the Commission is the senior member belonging to the Corps of Engineers.

SENATE COMMITTEE OF 1897.

A SPECIAL committee was appointed by the Senate in March 1897 to investigate and report upon the causes and prevention of floods on the Mississippi. The following interesting conclusions are taken from a newspaper synopsis of their report published December 1898.

(1.) Nothing in the evidence obtained by the committee discloses the fact that the destruction of timber near the head waters of these river systems tends to cause or promote floods.

(2.) Reservoirs in the head waters repress to some extent floods in river bottoms of the head waters, but have no material effect upon floods or navigation on the lower reaches of the river.

(3.) Sites do not exist for reservoirs of size sufficient to withhold and control the great freshets on the lower river.

(4.) The experience of 1896 indicates that a complete enclosure of all the river basins with levees will necessitate the raising of the Lousiana levees by three to four feet, and of the Yazoo levees by four to six feet.

(5). The completion of the levee system, from the head of St. Francis Basin to the head of the Passes, is estimated at from eighteen to twenty million dollars, with which expenditure the committee consider that levees sufficiently high and strong can be constructed to afford complete protection.*

(6). Such good results in assisting navigation have been obtained with the new hydraulic dredges that the committee recommend ample provision be made for continuing this work.

(7). The opinion is expressed, that in view of the great cost, comparatively great taking into consideration the results, it would be more judicious to limit revetment work to levee and harbour protection. Revetments are undoubtedly very efficacious, but the cost is so immense that a systematic application of them is scarcely warranted. Contraction by means of jetties, dikes, and dams, supplemented by dredging, seems to have given the best results with the least cost.

(8). The improvement of the south-west pass by the construction of jetties at its mouth is recommended as the best means of ob-

* The expenditure on levees, up to the present, is quoted at $47,500,000.

taining a deeper and broader channel to meet the wants of modern vessels drawing from 27 to 30 feet of water.

(9). The systematic improvement, by reaches, of the Missouri River is recommended to induce on it traffic by steamboats and barges in order to render it impossible for railroads to monopolize freights.

River Front, New Orleans.

CHAPTER II.

Survey of the Mississippi River—Gauges—Discharge Measurement—Sediment Observations.

SURVEY OF THE MISSISSIPPI RIVER.

BETWEEN 1870 and 1883 a general survey of the river from Cairo to Donaldsonville, 885 miles, was made under the directions of the Mississippi Commission, and since the latter date it has been completed south to the Gulf and north for a considerable length of the Missouri and up the Mississippi as far as St. Paul.

The objects of the survey are, as stated in instructions issued by the Commission, "to obtain sufficient data for an accurate topographical and hydrographical map, which may be used in studying the physical characteristics of the river, planning improvements, and also serve as a basis for future surveys by means of which the changes in bed and banks may be ascertained and their causes and effects studied."

Mr. Ockerson who, as Assistant Engineer in the Secretary's office, had charge of these surveys, explains, in the introductory remarks of his paper on erosion of river banks, that it comprised a system of secondary triangulation, by means of which stone monuments were located at different intervals along the river to serve as initial points for all future surveys. On these points careful topographical surveys were based, and additional stone survey marks set, marking sections of the channel at intervals of three miles along the river. On these lines there were usually placed stones, two on each side of the river, at distances back from the banks of one-quarter and three-quarters of a mile respectively. These lines are called "stone lines."

A line of precise levels was also carried along the river and permanent bench marks fixed, from which the elevations on stone lines and secondary points were derived.

Thus a large number of points have been established, the position and elevation of which are well determined.

By using these fixed points in new surveys it is an easy matter to determine with great accuracy changes in the bank lines.

The original plates of the surveys are on a scale of 1 to 10,000; these are reproduced as printed maps on a scale of 1 to 20,000. In addition, the commission have published a general map of the river, scale one inch to the mile, and a still smaller scale map one inch to five miles. A reduced sample sheet is given opposite. The larger scale map is probably the finest, most correctly and completely finished river map ever published.

Regarding this special survey work of the Commission, Mr. Coppee in discussing Mr. Starling's paper on Discharge of the Mississippi, remarks: "The investigation relative to the physical phenomena of the Mississippi River instituted and being carried on by the Mississippi River Commission is an engineering work second in importance to none that has been undertaken in the present century."

Tertiary Triangles.

Where the secondary triangulation stations are more than three miles apart a tertiary system is laid out, giving points on either bank at intervals of a mile or so; these form the basis of the topographical survey. The river ends of the stone lines are made points in the tertiary triangulation system.

Topography.

The detailed topography covers a belt on each side of the river, in wooded country or on bluffs about one-half to three-quarters of a mile wide, and in open country from one to two miles in width.

In this area are located with transit and stadia all points needed to accurately plot important features on a scale of 1 to 10,000. Beyond the above limits outline surveys are made defining streams, lakes, the foot and crest of bluffs, within a limit of ten miles of river. Within the limits of the detailed area are located the top and bottom of the river bank, the shore line of islands and bars, banks and water lines of all waterways and lakes, approximate limits and kinds of cultivation, and forests, roads, levees, houses, fences, etc. A sufficient number of elevations are determined on the bottom lands to admit of plotting contours five feet apart. When the river is at a high stage the survey is confined to buffs and lands above overflow, until such time as the stage is favourable for hydrography and survey of the bars and low lands; then the ground is gone over a second time.

All water gauges are connected by levels with the nearest precise level bench marks.

REDUCED SAMPLE SHEET.

SURVEY OF

THE MISSISSIPPI RIVER,

FROM CAIRO AND VICINITY TO THE

MISSISSIPPI RIVER COMMISSION,

CHART No. 118.

Prepared from a Topographical Survey,

Made in 1881

AUTHORITIES

The Topographical and Hydrographical Survey was executed under the direction of Brevet Lieut.-Colonel C. B. Comstock, U. S. A., Secretary Mississippi River Commission. The Secondary Triangulation, in 1881, by Assistant Engineer, C. L. Hoffman, U. S. A. Field Astronomer, Lieut. J. Lewis, Corps of Engineers, U. S. A. Assistant, Mississippi River Commission.

Latitude and Declination are derived provisionally from the Coast and Geodetic Survey Chart No. 1, by Lieut. J. Lewis, Corps of Engineers, U. S. A., and Asst. Civil Engineer, E. H. Adams, Corps of Engineers, U. S. A.

Secondary Triangulation, in 1882, by Assistant Engineer, C. L. Hoffman, U. S. A.

Primary Levels, in 1881, by Assistant Engineer, J. A. Tripp and A. W. Bayliss.

Topography and Hydrography, in 1881, by Assistant Engineer, A. W. Bayliss, Corps of Engineers.

Reference level by T. L. Osborne and C. E. Allen.

Prepared for U. S. Engineer Office, St. Louis, Mo., by Capt. G. J. Fiebeger, U. S. Engineer and H. Gannett, Drafting Q. M. Clerk.

Hydrography by R. L. Vernon, U. C. Rutledge and L. O. Colbert.

Other Assistant and Draftsmen under the direction of J. J. Cowdery, Assistant Engineer, in Charge of Survey, by C. L. Crosby, W. Crawford, H. Gannett, C. E. Allen, and L. O. Colbert.

The outline of the Mississippi River was copied from Maps of the Mississippi River Commission.

SCALE

Statute Miles

NOTES.

Soundings are given in feet above the Memphis datum plane, which is 0.5 feet below the zero of the Cairo gauge, and 0.3 feet below the approximate mean low water surface at Cairo, Ill., and Columbus, Ky.

Soundings were made over ranges four miles apart in the middle and five miles apart in the bends of the river. The positions of the ranges across the Mississippi River are indicated by figures on the shore lines, and the positions of the lines in the bends are indicated by the letters.

Lines of intermediate sailed soundings, giving sufficient information for navigation, are shown by dotted lines. The soundings on these lines are not given in the tables, but are shown on the chart. The topography and hydrography of the river banks, and the location of the bottom lines, also the location of the triangulation stations, were plotted from the descriptions of the lines in the tables. The soundings were then plotted from the descriptions indicated by the dotted lines.

The above line-level referred to the origin of the soundings, but is plotted on a different.

Soundings are corrected to low water as indicated by the scale, which is 0.5 feet below the zero of the Memphis gauge, and 0.3 feet below the zero of the Cairo gauge, and 0.1 feet above the zero of the Columbus gauge. The low water surface is determined from the Memphis gauge, and the Cairo gauge between Cairo and Columbus. The low water surface between Columbus and Memphis is determined by the slope of the water surface between Cairo and Memphis.

The readings, by feet, on the bottom gauges, on the days of soundings, were as follows:

Aug. 1, 1881,	22.1,	Aug. 7, 1881,	22.7	Aug. 21, 1881,	22.3
" 2, "	22.2,	" 8, "	22.7	" 22, "	22.2
" 3, "	22.3,	" 9, "	22.7	" 23, "	22.1
" 4, "	22.4,	" 10, "	22.7	" 24, "	22.0
" 5, "	22.5,	" 11, "	22.7	" 25, "	21.9
" 6, "	22.6,	" 12, "	22.7	" 26, "	21.8

The mean stage of the soundings, as they stand as plotted from the above readings is 22.3 feet.

Notes in the river text indicate the days on which soundings were made.

The high water of 1882 on the bottom gauge was 57.4 feet, and that above the datum, and the low water of 1881, on the same gauge, was 1.00 feet below zero of the datum.

INDEX CHART.

NOTES.

Elevations are given in feet above the Mississippi datum plane, which is 100·64 feet below the datum of the U. S. Engineers gauge at Memphis, Tenn., and approximately 9·15 feet below mean Gulf Level at Biloxi, Miss.

The contours are drawn one twenty-foot apart on the bluffs and five feet apart on the bottom lands and river banks. The elevations of the contours above the Memphis datum are indicated by figures which are placed on the higher side of the lines to show the direction of the slopes.

Lines of benchmarks called deep lines, giving soundings of the river, are shown on the sheet by dotted lines. They are numbered consecutively from Cairo, Ills., northward. The benchmarks are stone posts or iron pipes set on flat tiles. The upper figures preceding the slope □ indicate the number of the stone tile, and the lower figure gives the number of the benchmark on the line; the numbers following are the elevations of the tiles or pipes. The benchmarks have their elevations indicated in a similar way.

The shore line is not referred to the stage of the soundings, but is plotted as surveyed.

Soundings are expressed in feet, and are reduced to the sounding stage of water on the days when the soundings of the sheet were made. Thebaut's at Portage, Mo., is 412·5 feet above the datum plane and the lower workers has an average slope of 0·65 foot per mile between Cairo and Thebaut's. The high water slope between successive stone lines is as follows:—41 to 42=0·56 foot; 42 to 43=0·56 foot; 43 to 44=0·56 foot; 44 to 45=0·56 foot.

The readings in feet, on the Grafton gauge, on the days of sounding, were as follows:—

Aug. 1, 1901	12·1	Aug. 7, 1901, 10 P.M.	12·4
" 14, "	12·2	" 15, "	12·2
" 21, "	12·2	" 28, "	12·2
" 31, "	12·3		

The mean stage of the soundings on this sheet as derived from the above readings is 12·3 feet.

Below is the clear bed indicate the days on which soundings were made.

The high water of 1901 on the Grafton gauge was 37·4 feet—437·7 feet above the datum, and the low water of 1900, on the same gauge, was 382·9 feet—433·5 feet above the datum.

INDEX CHART.

LITH. TROWBRIDGE, SHEAP & CO., CALCUTTA

The topographical survey is carried out entirely with transit instruments and stadia rods, the plain table not being used at all. A quick observer will keep two or three stadia men busy giving him points in flat open country; both chain and levelling instruments are dispensed with. The rate of progress by a well organized party is claimed to be far ahead of that usual in any other system, while horizontal distances are as accurately obtained, as a rule, as by the chain, and levelling may be done within a few tenths of a foot in a mile, sufficiently accurate for topographical purposes.

Topographical survey by this method, the writer believes, could be taught with advantage to the Public Works Department in the Indian training colleges. Certainly no better results could be desired than those obtained by the surveyors of the Mississippi River.*

Hydrography.

The hydrographic survey of the river includes the cross sectioning between banks at about every 250 meters length of the channel, in addition to detailed survey of bars, bends, crossings, etc., where special information is required in connection with proposed works of conservation or protection. The fixed points of reference for the survey are connected with the triangulation of the topographical survey; in fact the topographical and hydrographical surveys are carried out simultaneously in the original survey of the river.

Cross sections are taken on sounding or range lines normal to the streams and numbered consecutively. The character of the bottom is determined by means of a tallowed lead. On all crossings sufficient soundings are taken to determine the least channel depths between pools. For soundings less than 10 feet in depth a pole divided into feet and tenths is used; in water from 10 to 20 feet in depth a 10 to 12 pound lead, and for greater depths a 15 to 20 pound lead. The line is of hemp, $\frac{3}{8}$ of an inch in diameter, with leather or cloth tags at every foot of length, and special tags at the 10 feet points.

The cross section line is fixed by arranging posts in line or in range along the banks of the river, two on each bank where it is of great width; but in narrow reaches merely two posts on one side suffice to keep the range on which the soundings are to be taken.

* For more detailed information on the practice followed in the Survey of the Mississippi, see Appendix A—"Instructions to Assistant Engineers and others for Field Work—Survey of the Mississippi River" by the Secretary of the Mississippi Commission, dated February 28th, 1899.

Locating Soundings.

Different methods are adopted for locating soundings; the common practice is to locate as many as possible by angles read simultaneously between located points on shore with two sextants in the sounding boat. The location of intermediate soundings are interpolated by taking them at time intervals, or the soundings are located by intersections obtained by two transits observing from different points on shore.

It may be useful to describe here more fully the different methods of locating soundings adapted to different conditions and objects. Quoting from Mr. Johnson's concise article on this subject: "The location of a sounding can be found with reference to visible known points by (1) Two angles read at fixed points on shore. (2) Two angles read in the boat. (3) Taking the sounding on a certain range and reading one angle either on shore or in the boat. (4) Sounding along a known range, taking soundings at known intervals of time while rowing at a uniform rate. (5) Taking soundings at the intersection of fixed range lines. (6) Means of cords or wires stretched between fixed stations, these having tags where the soundings are to be taken."

(1) Two angles read on shore. If two instruments be placed at two known points on shore and the angles subtended by some other fixed point and the boat be read by both instruments while the sounding is taken, the intersection of the pointings to the boat, when plotted on the chart containing the point of observation, will be the plotted position of the sounding. When the angles are read shore signals should usually be given preparatory to taking a sounding and also when the sounding is made. If, however, soundings are taken at regular intervals, preparatory signals may be omitted, and the flag shown only when the sounding is taken. The instrument may be set to read zero and pointing to the fixed station to simplify the reading of the angles.

The objection to this method is that it requires two observers, who must be transferred as the work proceeds, in order to maintain good intersections, or in order to see the boat at all times.

(2) Two angles read in the boat. Two angles read in the boat to three points on shore whose relative positions are known give what is called 'the three-points problem." If the three known stations be plotted in position, and the two observed angles be carefully set on a three-armed protractor, then, when the three radial edges coincide with

the three stations, the centre of the protractor circle corresponds to the position of the point of observation. This is the common method of plotting soundings. (When two sextant angles are read from the sounding boat, a special double sextant can be used with great convenience. That known as Wood's had been devised to read both angles simultaneously.)

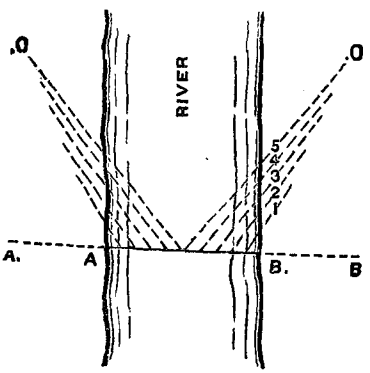
This method of locating soundings is used by both the American and British hydrographic departments for coast surveys. Where a double sextant is not available for river work, two sextants, with two observers, are advisable in order to obtain correct results.

(3) One range and one angle. In this method a base line is set off along the shore from the end of which angles are read while the boat is kept on the range line.

(4) One range and time intervals. This method is suitable only for soundings in still water where a boat can be pulled with uniformity of speed.

(5) By means of intersecting ranges. This method is adapted to the case where soundings are to be repeated many times at the same place, and is commonly adopted when the object is to study the changes occurring on the bottom, or for measuring discharges on the cross section of the river, where it is essential that successive soundings should coincide in position.

Range posts are fixed on the line of the section, then a series of ranges are marked out from a pivot point some distance above or below the section, and the intersections of the pivot ranges with the section ranges give the sounding points. The soundings can then be made at the same points continuously without observing any angles at all.



The marginal sketch explains itself. A. B. is the range line. O. O. are pivot points. Poles 1, 2, 3, 4, etc., are so fixed that in range with the pivot points they give intersections with A. A. or B.B. at the sounding points.

(6) By cords and wires. This method is only applicable to a narrow channel across which graduated lines or wires can be stretched to locate the position of soundings.

Sounding Boat.

In a moderate current soundings may be taken from a row boat of the cutter pattern, having in the bow a rough platform for the leadsman to stand on. The crew would consist of six oarsmen, with two observers and one recorder, one of the observers acting as coxswain. In depths up to 60 feet soundings have been made without checking the boat, the leadsman casting the line far enough forward to enable him to reach bottom by the time the line becomes vertical.

When the depth or current make this impossible, soundings are taken while drifting without entirely drawing up the lead. For soundings in a strong current a steam launch which can be held on the range line without difficulty is preferable.

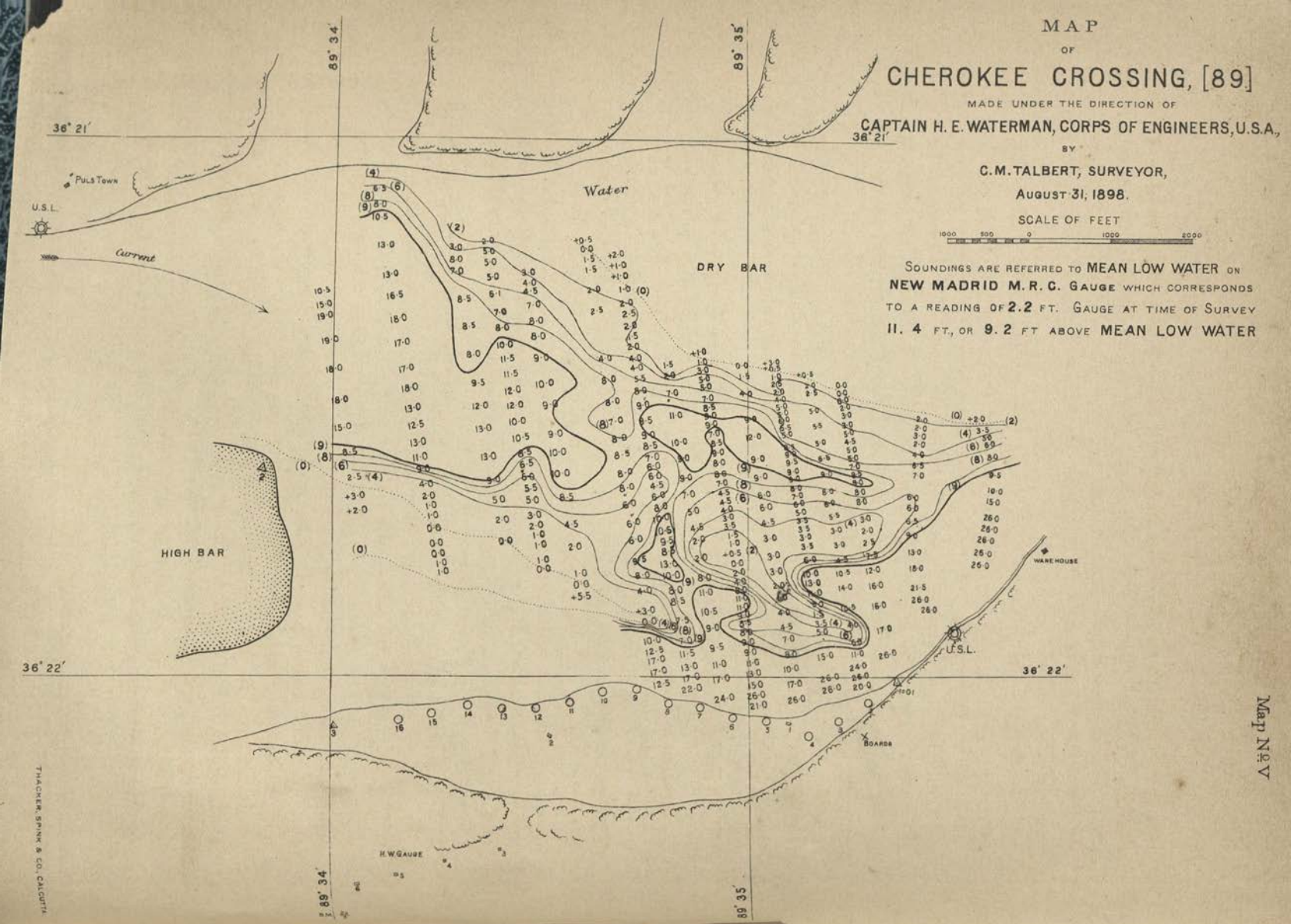
A launch or steamboat is almost always used on the Mississippi for current meter observation taken in conjunction with soundings for discharge measurements.

Supplementary Surveys.

In addition to survey work for the preparation of the regular charts of the river referred to above, it is customary to make regular "fall" surveys of reaches of the river in which any special improvement works are being, or have lately been, carried out, in order that the effect and condition of such may be watched. For instance, to secure accurate data showing in detail the configuration of accretions and bottom, as well as direction and velocity of flow near permeable dikes constructed in 1897, a party was organized and continuously engaged for over two months on a special reach of the Missouri River.

Levels were run to show the dry contours for each foot in elevation of accretion on both banks; several sets of located soundings on special parallel ranges, fifty feet apart, were made. Two or more sets of very careful soundings were made about the head of each dike, five feet apart for a distance of 200 to 250 feet, on lines radiating from a point on the dike at the shore line or near its outer end. The radial lines were uniformly three degrees apart, and within the stated radial limits all of the waterway at each dike was sounded. Thus, at dike No. 2 the space sounded covered the area included in a circle 400 feet in diameter.

The soundings were made from a skiff at tags spaced 5 feet apart on a steel cable. The cable was stretched taut from a pin at the centre for the radial lines to a skiff anchored in the stream, the skiff, by


MAP
OF
CHEROKEE CROSSING, [89]
MADE UNDER THE DIRECTION OF
CAPTAIN H. E. WATERMAN, CORPS OF ENGINEERS, U.S.A.,
BY
C. M. TALBERT, SURVEYOR,
AUGUST 31, 1898.
SCALE OF FEET
1000 500 0 1000 2000
SOUNDINGS ARE REFERRED TO MEAN LOW WATER ON NEW MADRID M. R. C. GAUGE WHICH CORRESPONDS TO A READING OF 2.2 FT. GAUGE AT TIME OF SURVEY 11. 4 FT., OR 9. 2 FT ABOVE MEAN LOW WATER
89° 34'
89° 35'
36° 21'
36° 22'
Water
DRY BAR
HIGH BAR
Current
PULS TOWN
U.S.L.
WARE HOUSE
BOARDS
H.W. GAUGE
THACKER, SPINK & CO., CALCUTTA

Map N°V

means of a system of anchors and buoyed lines, being firmly held in a fixed position which could be adjusted by means of reels to the exact radial line indicated by a transit set over the centre. On both reaches several sets of current floats were run past the dikes, and their paths and velocities noted.

From the notes made twenty charts were plotted, and of these six were selected as good examples for study of the influence of permeable dikes upon conditions of flow. Mr. Fox says that the relation between dynamic head and velocity, as algebraically expressed by $\left(H = \frac{1}{2g}v^2\right)$ is hardly more positive than the train of effects that follow a given head of a permeable dike in the Missouri River, and are made manifest in the configuration of the bottom and current lines.

For example, the reason for the formation of a middle ground in a reach of improved river, the banks of which are defined by dikes, is made apparent; and it is also an observed fact that mid-flow is attracted rather than repelled.

Special Survey.

Some special survey is always necessary for the location of the cut to be dredged through a bar on a crossing, or between two pools for the deepening of the channel. The writer was much struck by the speed at which such surveys are made. The men employed on this duty are, however, thoroughly trained and very competent. A party in one and a half days can completely survey and plot close-soundings over a length of from one to one and a half miles of river. The writer saw results of a survey made by one party, in which 750 odd soundings were taken in five hours and the survey plotted by the evening of the same day on which the soundings were taken.

Excellent style of the Mississippi Maps.

Before concluding his remarks on this subject, the writer would draw particular attention to the manner in which the Mississippi River maps are got up. The lithographed maps, scale 1 to 20,000, are on a reduced scale facsimile reproductions of the original charts of scale 1 to 10,000. The excellence of their style and finish is largely due to the uniformity and neatness of the conventional signs and to the absence of freehand work in the lettering and figuring of the original maps. All of this filling in of signs, lettering and figuring is done by a stencilling outfit specially designed by Mr. Ockerson.

The appearance of a map or chart, on which a great number of figures of soundings and conventional signs are shown, depends largely

on the uniformity and style of the work. The writer saw the outfit being used, and Mr. Clark, Assistant Engineer in charge of the Mapping Department, Mississippi Commission, assured him that the speed at which lettering and figuring could be done with this outfit on a chart, scale 1 to 10,000, is at least 50% quicker than when done by hand, and the mapping work compares even more favourably. While, therefore, the results are so much better, the writer has no hesitation in recommending any mapping department to use such a stencilling outfit as the "Ockerson." The rollers would, of course, have to be made to suit the circumstances of each case, to embrace the conventional signs required.

The Ockerson Stencilling Outfit.

The complete outfit consists of a mapping device for conventional signs and a printing and lettering device. The former provides rollers to give impressions of the different conventional signs and the latter type letters and numbers in variety.

In a paper read before the American Society of Civil Engineers in 1895 Mr. Ockerson deals with the desirability of obtaining uniformity of style throughout a series of maps, and describes the experiments he made with different devices for printing conventional signs and letters for the projection of the survey of the river from Cairo to Donaldsonville, covering 2,800 square miles of country, and finally the production of his outfit to meet the requirement. In order to secure a uniform impression all over the maps, it proved necessary to use a stamp with a hard surface, which has also to be sufficiently elastic to print through a stencil.

The Ockerson Topographic Mapping Device.

A copper electrotype shell, backed with rubber about $\frac{1}{8}$ in. thick, is wrapped around a wooden cylinder of about $4\frac{1}{2}$ ins. diameter and 3 ins. length. An adjustable handle passing through the axis, giving it the appearance of a rolling-pin, completes the device.

"The roller is inked for each revolution by revolving in contact with an ink-roller. In printing, it is rolled slowly over the map, the amount of pressure being regulated by the force applied at the handles. It will be seen that the full size of one revolution of the roller will be 3 ins. × 13 ins., but many of the areas, such as fields, etc., are much larger than this, and as the joining of two impressions is easy to make by laying a piece of paper along the printed edge, and letting

the roller overlap a little, it was not thought best to increase the length of the cylinder as it would require more pressure.

"There still remained one difficulty in the way of rapid execution. The outlines of the map such as water courses, roads, etc., as well as the lettering, are necessarily put on the map before the signs. To print the signs and not interfere with these characters, which should remain clear and distinct, was quite essential. After trying several plans, such as covering with narrow strips of paper, etc., a pencil made of common starch was finally hit upon. This proved to be entirely satisfactory. To cover up a name, it is only necessary to pass the pencil over it once, and the ink on the stamp will not take on the starched surface. After the printing is done, the starch can be whipped off, leaving the name as clear as though it had never been touched.

"The various conventional signs required by the characteristics of the country mapped, *viz.*, woods, willows, grass, cultivated cotton, sugarcane, sand, etc., are now in daily use as above described. Before printing the chart, stencils are prepared for the whole sheet. Any thin transparent paper will answer for this purpose. An ordinary "antiquarian" sheet, covering about 900 square inches, can be prepared and printed in two days. The same work would employ a skilled draughtsman at least a month.

"Sand bars which are so tedious when made by hand, one dot at a time, can be printed to perfection, with the exception of the shading at the edge, which must be done by hand. Sanding, such as is used on hydrographic charts to show different depths, can be done with an absolute certainty that the tints will be the same throughout for each depth represented.

"For maps that are to be reproduced by photo-lithography, it is best to make the original large enough to admit of reduction to one half the scale. If it is desired to publish on the same scale, the printing can be done with lithographic transfer ink, and a transfer made to stone or zinc, from which any number of copies can be printed. In this case the outlining should be done on suitable transfer paper with autographic ink, and the names printed with transfer ink."

In using the stamps described above, it is desirable to work on a paper with a smooth, hard and highly calendered surface, so that the

impression will be clear and sharp. The best ink is the finest quality of "German printing ink." The annexed sheet of conventional signs and letters has been projected at the writer's request, with permission of the Secretary, Capt. Patrick.

The sample sheet is accompanied by a memorandum by Capt. Patrick, as follows: "Time—printing, lettering and figures on sample sheet, 1 hour. Time—preparing masks, and printing the signs, 2 hours 50 minutes. The explanatory designations, pasture, cultivated, sand, open, timber, etc., are not put on our maps, as the signs are sufficiently well known. They are placed on this sample for the benefit of those unacquainted with the signs." *

It will be seen that any character desired can be made and used in the manner described. Having the original drawing from which to produce the stamp, the work of the best draughtsman can be multiplied without limit, and not detract very much from the quality or style of the original. There are, of course, very fine grades of work, such as are used on small scale maps, which can only be done by hand. For ordinary work, the results are entirely satisfactory both as to quality and cost.

Lettering Device.—A stamp for putting on the letters and figures is a valuable adjunct to the device described above.

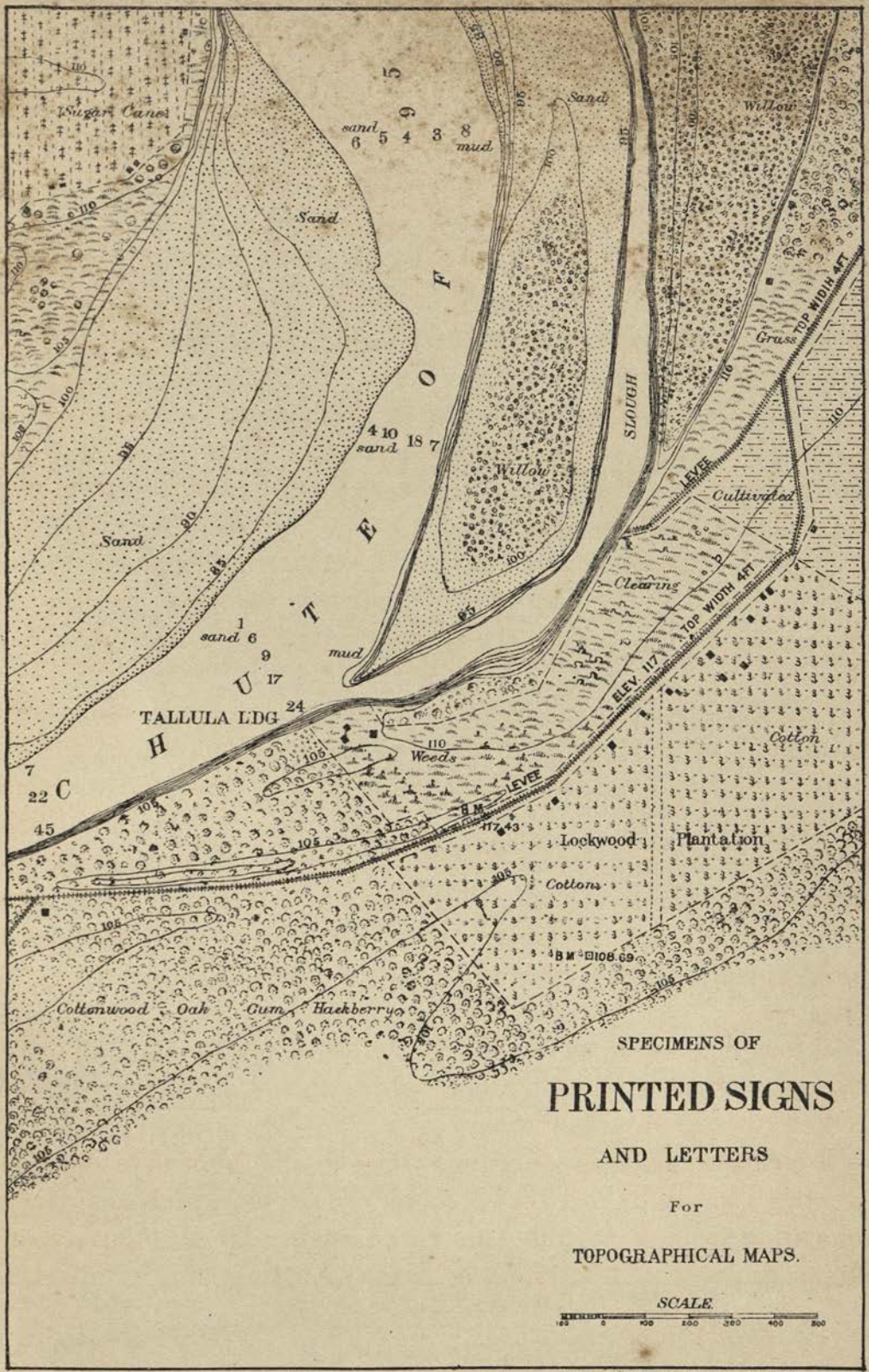
It consists of a type-holder, figure discs, these two parts being interchangeable, and a stamp. Common type of suitable size and style are used. For names, etc., words are "set up" in the type-holder, and held by a clamp screw. The base of the frame being at right angles to the line of the type in the holder, the names can always be printed parallel to the sides of the map by sliding the frame along a ruler.

Where the same word is repeated frequently on the map, the time saved is very considerable, while the quality of the work is excellent.

For figures such as soundings three discs are used, each of which bears the ten digits. They revolve on an axis, and with them any combination from 0 to 999 can be formed. These figures are also common type which are held in place by fitting snugly into the slots

* The original sheet has been forwarded by Government to the Director-General of Stores. That shown is a reproduction of a smaller sample given in Mr Ockerson's paper.

Map No. VI



LITHO. THACKER, SPINK & CO, CALCUTTA.

cut for them. When they become worn they can easily be replaced by new ones.

Cost.—The cost of the mapping device as quoted by the manufacturers, Messrs. A. S. Aloe & Co., 517, Olive Street, St. Louis, Mo., is as follows :—

A set of 7 signs of any of the designs in stock, in box to hold signs, ink plate, ink, and a set of. universal handles	$100·00
Additional signs of those in stock, each	15·00
Any specially made sign, if drawings are furnished, first one	15·00
Second one	15·00
A set of universal handles	2·50
Thus a complete outfit, with 15 signs, as used by the Mississippi River Commission, would cost ...	222·50
The cost of the Lettering device, with ink roller, plate and ink, no type, is quoted at	23·00
Type, such as in use by the Commission would cost from $5 to $8, extra, say	7·00
Total cost of Lettering device	30·00
Grand Total cost of complete outfit	252·50

GAUGES.

By the stage of a river is meant the height of the water surface at a given point above or below a fixed plane of reference.

In nearly all cases of gauges fixed by the Commission the plane of reference is an arbitrary one, supposed in each instance originally to have been at or about lowest water level of the river at that point at which the gauge was fixed. In few cases, however, does the plane of reference coincide now with extreme low water.

Permanent gauges have been fixed at points where tributaries enter and at important intermediate stations from 40 to 50 miles apart on the whole length of the Mississippi between Cairo and Fort Jackson. In all there are 26 such gauges in this length of river. The important tributaries also have gauges fixed on them.

These gauges are read twice daily, and bulletins of the stage of water, at each gauge, are published for information of river pilots. Readings are taken by an observer at 8 A.M. and 4 P.M. daily, and when taken are immediately entered in the gauge book and recorded on postal cards addressed to the Secretary, copies or duplicates of these cards being also posted to the District Engineer.

The gauges have been erected or built on permanent bluffs, or on more or less permanent banks of the river which are there held by heavy revetments. The gauge usually consists of a graduated iron plate, screwed to timber balks about 12 to 14 inches square, which are laid on the slope of the bank in line with the face of the pitched revetment. Gauges are also attached to piers of bridges at St. Louis, Cairo, &c.

Bulletins.

The bulletins show the stage of the river to the nearest quarter of a foot, and the letters R. F. S. signify whether it is rising, falling, or steady. Thus, 24¼ F. on a bulletin board signifies that the gauge at that point reads 24 feet 3 inches, and that the river is falling. Bulletins are changed morning and evening whenever there is a change of stage to record.

The bulletin board is a wooden frame erected on posts on the river front, at a height of a few feet above flood level. The figures and letters are painted white, on a black background, on wrought iron sheets

Memphis, Tenn, April 13, 1897.

about three feet in height by two feet in width. They can be read by the naked eye on passing steamers at a distance of from a quarter to half a mile away. Fractions of a foot, not decimals, are posted.

High Water Gauges.

In addition to these permanent gauges, self-recording high water gauges, at intervals of five miles, have been erected between Cairo and Fort Jackson. There are in all 182 of these ; they record merely the highest level reached by the flood each season. They consist of painted graduated posts, erected at or near top water level, each painted post being enclosed in a vertical box, provided with holes for the inlet of the water, for the protection of its surface. The record of the flood is merely the disfigurement of the paint left by the water mark on the clean surface of the gauge.

These self-registering gauges are said to be of considerable value in recording maximum flood level, as they give more reliable record than water-marks on trees or levee slopes, the latter being usually not within some inches of the maximum stage reached by a flood.

Tide Gauges.

Self-registering tide gauges are also maintained at Biloxi and Fort Jackson.

All gauges are inspected by a steamer party three times yearly, whose duty it is to keep them and the bulletin boards in proper repair. The planes of reference or zeros of the several gauges have been connected by precise levelling, and their elevation reduced to what is known as the Memphis datum, thus enabling the general slope of any stage of the flood to be correctly calculated.

Daily record is kept of each gauge and its hydrograph is plotted and recorded in the District Office concerned.

DISCHARGE MEASUREMENT.

THE method now generally adopted for measuring the Lower Mississippi is by current meter from a steam launch, using one observation at $\frac{6}{10}$ths of the depth as the mean velocity on a vertical. Soundings and velocities are taken at different points along the section, from which the flow of each partial area is calculated, and the sum of these partial area discharges gives the whole discharge of the cross section.

Six-tenths depth observation.

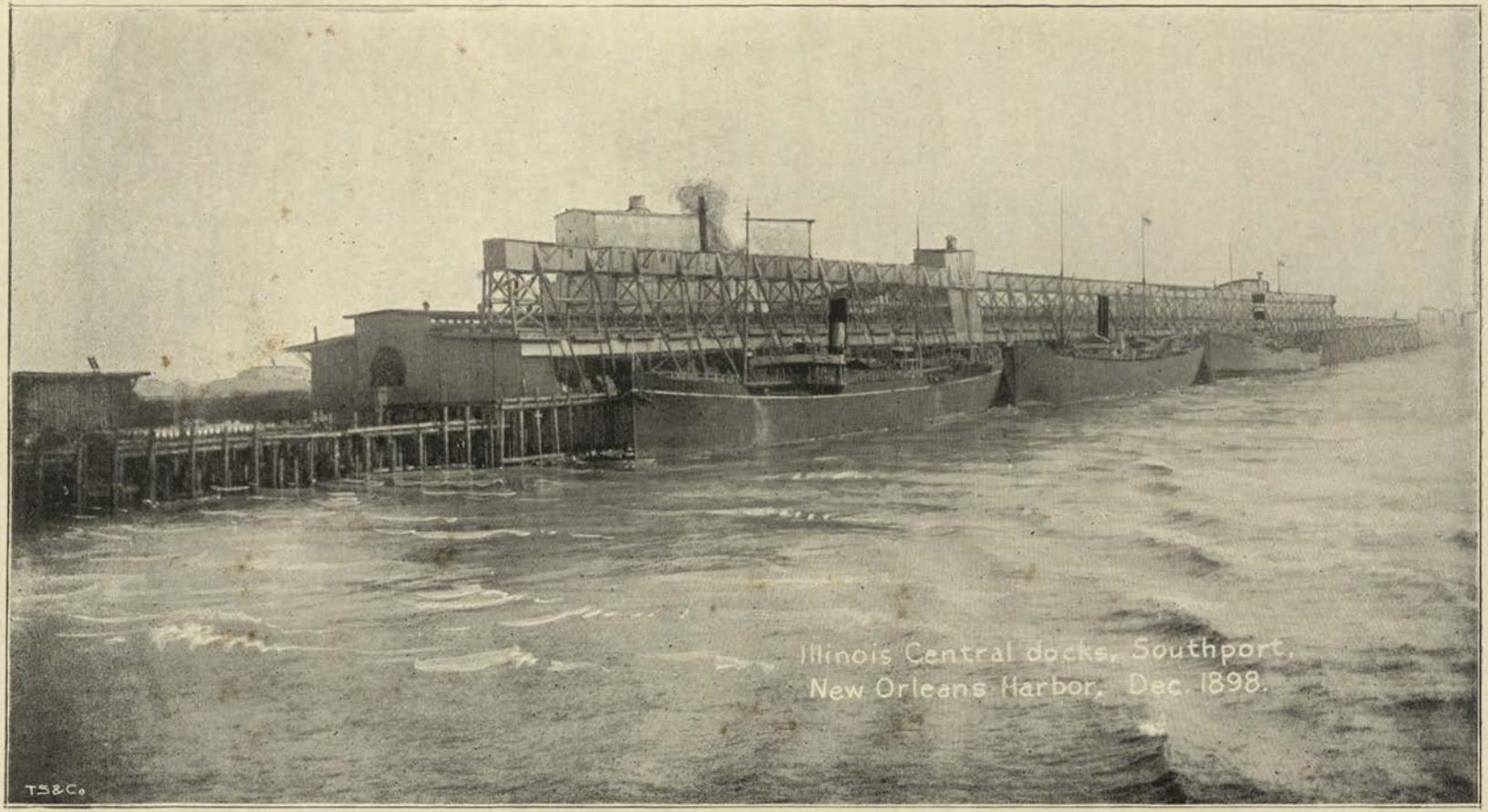
Six-tenths the depth, as the point of observation for the mean velocity, has been arrived at after long experience and special investigation of velocities on different points of the vertical. There is something to be said against it still, but the preponderance of opinion is to the effect that it facilitates so much the obtaining of a whole series of observations within a reasonable time that the result obtained for the whole discharge is probably a closer approximation to the true discharge than if a great number of observations were made. The great number necessary to obtain exactness would occupy a longer period during which occur change of stage and alteration of the bottom, with variation of velocities, thus vitiating the accuracy of the detail when applied to the aggregate results.

The current meter.

The current meter is now generally recognized as the most accurate instrument for obtaining sub-surface velocities; though until quite recent years submerged floats or rod-floats were used on the Lower Mississippi when choice in such matters was left to the discretion of the District Engineer, and they are still used on some stations of the higher river and tributaries. The system of taking discharge observations at present in vogue on the Lower Mississippi, under the control of the Commission, is by current meter with occasional float observations as a check.

History.

Since the days of Humphreys and Abbot there have been many changes in the methods followed for obtaining measurements of the river's discharge. The writer cannot attempt to give a complete history of experiments or their



Illinois Central Docks, Southport, New Orleans Harbor, Dec. 1898.

results, but he proposes to note briefly the more important features of the practice of late years.

Humphreys and Abbot calculated their discharges on the assumption that the bed of the river was permanent at the gauge site, and having once taken its cross section it was comparatively easy at different stages to calculate discharges, if correct coefficients were applied for reduction of the mean from the observed velocities. Their assumptions are, however, now known to be wrong, not only as regards permanency of cross section, but in the coefficients applied to velocities. Special observations of the movement of sand waves, and of changes on the bottom, have shown that the area of the cross section changes from day to day; and that, therefore, all discharge measurements of a river of this description require not only observation of velocities, but calculation of the area of the cross section for each complete measurement. The observed movement of sand waves of height as great as ten feet, with a daily travel of as much as thirty feet, is recorded in the proceedings of the Commission.

Since the organization of the Mississippi Commission in 1879, more or less continuous measurements of discharges have been made at certain points on the river, and at special places where high and low water discharges were thought of particular interest. The extent of these observations has varied according to the allotments of funds available. In the earlier years measurements were made at six or seven stations. For two or three years fewer stations were maintained; then from 1890 to 1894 as many as ten to twelve parties were employed, and since the latter date special high and low water observations have been made at different places. The results have been published in the reports of the Commission with, in some cases, exhaustive reports on the methods followed; and it is from the long experience of these observations that the present system has been adopted as the best suited to the circumstances.

Rods, floats and meters.

Though experience has shown the current meter to be the best, yet when such is not available, or in smaller rivers or large canals of regular cross section and even flow, rods or floats may be resorted to for current observations. The developments of these will therefore be first described.

The mean velocity of a stream, or of a partial area of a cross section, is that velocity which, multiplied by the area, will give the

discharge through the cross section considered. It is really the mean of the velocities of the filaments moving through the area under consideration, but it is not an actual velocity, though it may coincide with the velocity of some one or more of the filaments.

By the use of the rod float an attempt is made to obtain at one observation the mean velocity on a vertical. The submerged float is supposed to give the velocity at the depth at which the float moves, and the mean of a series of these is taken as the mean velocity of the whole. The meter is used in the same way as the submerged float, but with better results.

Rod floats.

The rods may be either wooden or tin, loaded at the bottom, and of length to suit the channel in which they are to be used. Theoretically they should reach to the bottom of the channel to give correct results; that is, in order that the rod may record the mean velocity of the filaments in the vertical, it should be of the full depth of the water. It has, however, even in channels of uniform section, to be kept less than the depth, and in channels of uneven bottom considerably less, in order that it may float freely. Obviously, therefore, it is unsuited for use in rivers of irregular depths and section, and in artificial channels cannot be advantageously used where depths are greater than about 25 feet. As a matter of fact rods have been used in depths considerably greater than their own lengths, thus obtaining merely the mean of the upper velocities; and, in such cases, a co-efficient has to be applied to reduce the mean velocity of the full depth of the vertical considered.

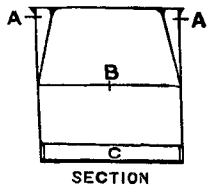
Submerged or double floats.

The object of a submerged float being to obtain a velocity of a filament moving at uniform depth below the surface, the ideal float should consist of a body having its floatation regulated to maintain it at the required depth without exposing any appurtenances of the float to the influence of filaments above the point of observation. Unfortunately, to watch its movements, it is necessary to attach it to a surface float or buoyed flag, and a submerged float therefore consists of the lower or sub-floats and a small surface float, or buoy, bearing a flag.

Double floats used in 1897.

From a compilation, made by Mr. Wheeler, of Extracts of reports on discharge measurements of 1879, it appears that improved floats were introduced in that year at

Hampton Landing, Ark. The sub-float consisted of two hollow iron cylinders, the outer one twelve inches long by ten inches in diameter, and the inner one, of half the length of the outer one, tapering from ten inches at the base to eight inches at the top. The space between the two when closed in at the top thus forms an air chamber. The lead for ballast was soldered to the inside of the bottom of the outside cylinder, see sketch in the margin.



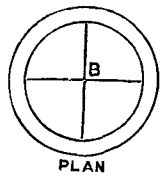
SECTION

A, A, is the air chamber.

B, a wire across for attachment of connecting wire or chord.

C, the lead ring.

The disposition of lead around the bottom, together with the favourable slope of the air chamber, facilitates the descent of the sub-float when dropped into the water and renders it less susceptible to the influence of whirls and boils.



PLAN

The surface float consisted of a cylinder six inches long and four and a half inches in diameter, with conical ends. The cones had altitudes of three and four inches respectively, and the loop to which the cord was attached to connect with sub-float was placed near the acute end. This form gave great buoyancy and offered little resistance to any other than a vertical pull on the cord, and permitted the sub-float to exercise control over the movements of the surface floats, a matter of great importance, as the velocity of the sub-float is determined by locating positions of its surface float.

This float resisted the water pressure successfully, and was quite satisfactory for depths not exceeding 40 feet. Beyond that it collapsed, and a specially strongly made float, which contained as many as 16 air chambers, was subsequently devised. The cord finally adopted for connecting the surface and sub-floats was a braided silk, size C. Its diameter was ·05 inches, and breaking strain about 36 pounds. Oiled silk and linen were also tried, but none appeared so durable for the same thickness as the one adopted.

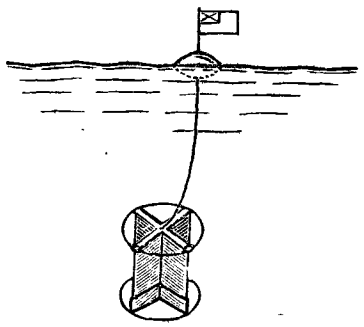
The volume of the surface float was 135 cubic inches, and its weight with flag ·85 pounds. Its buoyancy was thus 4 pounds in river water. The displacement by the sub-float, when submerged, was about 73·5 cubic inches, corresponding to a buoyancy of 2·65 pounds.

Its weight in air was 5·7 pounds, hence weight in water, or pull it exerted on the cord, was about 3 pounds.

Although the weight of authority appears to favour a sub-float of about the same density as water, it is pointed out that the locating of position of the sub-float relative to that of its surface float, not only in the horizontal plane, but also as to depth, demands a tension on the cord to resist the tendency to variation from the vertical due to different velocities or to the effect of wind on the surface float. It also necessitates weight in the sub-float to counteract the effect of upward currents.

The next development in sub-float seems to have consisted merely in the reduction of its diameter from 10 inches to as little as 6 inches, thus increasing its power to withstand pressure, and make it more suitable for greater depths. The surface float is now commonly made of galvanized sheet iron, circular in plan and elliptical in cross section, the major axis being about 10 inches and the minor being about 5 inches. On the top of this is fastened a small wooden stick bearing a flag, and on the bottom of the float is a small hook to which is attached the silk cord which supports the sub-float.

For comparatively shallow waters, such as tributaries, the sub-float is often made merely of two rectangular sheets of galvanized iron, each about 12 × 15 inches, fastened perpendicularly to each other and intersecting in their centre lines.



A good form of float is that sketched in the margin which provides for cylindrical air cavities along the upper edges, and lead weights along the lower edges of the vanes. The weights are arranged to give the desired tension on the connecting cord and to maintain the float in an upright position.

Float run.

The velocity of the current at any depth is determined by running the lower float at this depth, and noting the time required for the float to pass between two fixed range lines at right angles to the direction of the current. The float run, or distance between ranges, may be as little as 100 feet for tributaries and canals, or as much as 400 to 500 feet for river observations.

Rod floats are well adapted to small channels of uniform section.

Comparison of methods.

Double floats are suitable for large rivers, but they have the disadvantage of registering only the velocity of a small body of water at the depth of the lower float. One rod observation of sufficient immersion is probably as good as several float observations. A current meter observation is considered to be better than many float or rod observations for either large or small rivers.

The chief recommendation of rods and floats is that they are cheap, but, if a continuous series of observations is to be taken for any length of time, the extra cost of the meter outfit will be more than balanced by the satisfactory results and the facility in obtaining them given by the use of the current meter.

Current meters.

The meter at present in use on the Lower Mississippi is the "Haskell" which is found to be very satisfactory. A few years back the "Price" current meter was equally popular. Both have been considerably improved of late years, and a type of the former, known as the "Ritchie-Haskell" Meter, is fitted with a compass, and automatically records direction of current as well as revolutions of the propeller. Both are made in different sizes to suit varying velocities.

The apparatus consists of a current meter and its dead weight, a velocity register and timepiece, battery cells, and wire cable.

To take an observation the meter is lowered over a pulley block on the end of a boom projecting from the side of the steam launch, and the revolutions of the meter wheel are read off for the period of observation from the register which automatically records them.

Present methods and the six-tenths depth velocity.

Mr. Starling, in his paper on Discharges of the Mississippi read before the American Society in 1895, deals very fully with the difficulties of correctly ascertaining the discharge of a large river, the relative merits of floats and meters, the ratio between mean, mid-depth, and other velocities, etc.; and his valuable paper can be recommended to the enquirer who is sufficiently interested to wish to trace the reasons which have led to the adoption of present methods.

He finally expresses his opinion to the effect that, in the ordinary method, the assumptions that the six-tenths depth velocity represents the mean velocity in any vertical plane, and that the velocity varies

uniformly from station to station, "are in the grand mean probably correct;" though in individual cases they are likely to depart widely from the truth yet the errors are not necessarily accumulative and discrepancies, in individual cases, should not cause surprise.

The conclusion, as expressed not only by Mr. Starling, but by all other engineers, who have been consulted on this point, is that the present method is undoubtedly the best known suited to the conditions. The careful recorder, who is searching after accuracy, for instance Mr. Tully, Assistant Engineer in the Secretary's office, who has had charge of the computation and compilation of the discharge measurements for many years, would prefer to see more frequent checks than are commonly made; but, though such may be suggested as desirable, it is not always possible to insist on them in practice.

It is sufficient, for the purpose of these notes, to say that since 1884, the velocity obtained at six-tenths of the depth from the surface has been, and is being, used as the mean velocity of the vertical. This is sometimes checked by what is known as the "Flanking Method," which consists in starting from one side of the river with the current meter submerged to a certain depth, usually 20 feet, and slowly flanking, or moving, across the discharge range, having a record running continuously, and also noting the registrations and the times as each intersecting range is passed. A correction for the movement of the boat is necessary to obtain velocities in the direction of the stream at right angles to the range. It is expressed by the formula: $v = \sqrt{v^2 - u^2}$.

Selection of gauge site.

In selecting the gauging place in a stream it is advisable to first make a separate set of experiments upon the direction of local currents to avoid, as much as possible, sources of error due to deflected currents.

The general practice has been to locate the section on a narrow part of the river, in a straight reach, if possible, but this does not receive as much consideration as the width. Instead of this, the section should be chosen on a rather wide straight reach, where the currents are flowing nearly parallel to each other. The narrow river is under abnormal conditions; the water is forced in at the head of the reach, causing boils and eddies for some distance down stream.

The chief objection to a wide section is the length of time required for a discharge measurement, which, it is argued, permits of

the currents changing before the observation is completed. It is doubtful, however, whether the changes in a wide reach are as great, or as frequent, as in a narrow one. Even if such is the case, the difficulty can be overcome by an increase in the party of observers. The use of current meters in modern practice has so much facilitated the taking of observations that an addition to the width of the cross-section of the gauge site is not a matter of such serious consideration as formerly.

Taking the measurements.

The method of taking observations, and the points to which attention should be especially directed in the field operations of discharge measurements, are enumerated below.

The discharge measurement, consisting of determination of stage, velocity, and cross-section, should be completed in one day; thus, at fixed stations for regular observation, there would be one complete measurement daily.

The gauge should be read twice daily, to the nearest $\frac{1}{100}$th of a foot, and, with the mean, recorded in the field book. If a special gauge is fixed for the cross-section, its zero should be connected with the recognized datum of the river gauges.

The number of current meter stations should average, at least, one for every 200 feet width of the river. If apices develope in the velocities observed additional stations should be occupied.

The shore stations should not be more than fifty feet from the water's edge.

The launch should be anchored at each station, when practicable, without loss of time. Otherwise it can be held in position on ranges, longitudinally by the engineer and laterally by the steersman. The current meter apparatus should be examined, tested and made ready for operation before leaving shore.

On reaching the first station, when the engineer and steersman have indicated that they are in position, the meter is lifted and dropped over the stern, while a second man lowers away on the boom arranged to fall on the down-stream side of the launch at an angle of 45 degrees with the axis of the launch. The boom being in position, the meter is brought to the surface, and then lowered to the desired depth.

The meter is not drawn up between stations but, as each is occupied and the depth determined, it is lowered or raised the distance

necessary to give it the submersion required. The easiest way of placing the meter at any desired depth is by means of the pinion on the reel, from a table constructed to show the lengths corresponding to revolutions.

In taking up the meter the reverse of the lowering process is followed. The meter is first placed at the same depth to which it went when the boom was lowered, as indicated on the wire; the reel is then fastened, and the boom raised, a man standing ready on the stern of the launch to draw the meter in and lift it aboard.

The meter should beheld on each station at six-tenths of the depth for from two to five minutes. In addition to this observation for mean velocity, it should be determined occasionally by integration from surface to bottom and back to surface.

The meter must be properly rated at the beginning of the work. The time required for the wheel to come to rest, after being turned briskly with the hand, should be carefully noted; and, on daily repetition of this test, if any change occurs a new rating will be necessary.

The cross-section is determined by soundings not exceeding 100 feet apart for regular bottom, and 50 feet apart when the bed is in ridges. Soundings are taken with a three eight inch line, which should be thoroughly wetted and stretched before being graduated. It should be tested regularly and when found necessary to apply corrections of lengths, such should be noted against each day's observations Special care is necessary to see that the leadsman takes vertical soundings. Soundings not located by intersection of ranges are located by instrument, or by time interpolations.

All observations are recorded in regular note-books on the spot.

Record of field work.

Field computations are made on computing paper, or block-tablets, and carefully preserved. Results are entered at once in red ink in the note-books on the page containing the field notes.

Velocities and soundings are taken at the same time, the chief of the party noting the latter and a recorder the former. The recorder reads off the chronograph slips, and takes out the velocities. Each velocity is then multiplied by the depth at which it was taken, the products are added, and the sum divided by the sum of the depths. This gives, approximately, the mean velocity, which is submitted to the chief as soon as the section is sounded.

Field computation.

This method is applicable only when velocity stations are practically equidistant. When not so, the velocity curve is plotted, together with the section resulting from the soundings; then equidistant ordinates are scaled off and treated as above to obtain the approximate mean velocity.

When soundings are practically equidistant, the area is computed by adding together the intermediate soundings and half the sum of the end ones and then multiplying the sum by the mean interval. If soundings are not equidistant, ordinates are scaled off the plotted section and the area calculated as before.

The area thus determined is exact, and, when multiplied by the approximate mean velocity, will give the discharge close enough to enable the chief of the party to judge how his work is proceeding and to detect errors or anomalies which need correction or explanation.

This field computation forms part of each day's work, and should be thus completed. Discharges not calculated on the same day should merely be reported as "Field work of discharges," with explanation of the omission of its computation on the day of observation.

The final office reduction of discharge is more refined than the above, and will be described further on.

The printed instructions to gauging parties, issued by the Secretary of the Mississippi Commission, comprise all the above, with explanatory notes on several points. A copy of them is given in Appendix A.

Rating the current meter.

The current meter registers merely the revolutions of the wheel, and, before the velocity of the water can be found, the ratio between rate of revolution of the wheel and rate of motion of the water must be found for all velocities that are to be observed. This is called "rating the meter." The ratio is not constant but is a linear function of the velocity.

Current meters are usually rated by attaching them to a rod fixed a few feet in front of the bow of a light boat or skiff, which is rowed through still water over a measured run, the time occupied and the number of registrations made during the time on the run being noted. The length of run divided by the time gives the velocity of the meter through the water, and the number of registrations divided by the time gives the number of registrations per unit of time. The unit of time taken is one second, and of distance is one foot.

If the registrations per second are plotted as abscissæ, and corresponding observed velocities as ordinates, it is seen that the plotted points lie approximately in a right line, or the relation between the two variables can best be expressed by an equation of the first degree of the form $y = a\ x + b$, in which a is a tangent of the angle which the line makes with the axis of x, and b is the intercept on the axis of y.

Any two observations at different speeds would give values of a and b, but, to find the best or most probable values of these constants, a number of observations are taken.

Mr. Wheeler, Assistant Engineer, made a report in 1882, explaining his theoretical method of reduction by squares of the equation for rating and describing the method of reduction of observations. This method has since been systematically adopted on the Mississippi and may be given here, in abbreviated form, with advantage.

Reduction of formula.

The problem is to obtain from the given observed values of "x" and "y" the most probable values of "a" and "b."

Let L . . . . . = Length of run.
„ N . . . . . = Number of observations.
„ $t_1, t_2, t_3 \ldots t_n$ = Observed times in passing over the length L.
„ $r_1, r_2 \ldots r_n$ = Number of registrations in times t_1, t_2, etc.
„ $y_1, y_2 \ldots y_n$ = Deduced values of y.
„ $x_1, x_2 \ldots x_n$ = Deduced values of x.
„ y_0 . . . . = Arithmetical mean of y_1, y_2, etc.
„ x_0 . . . . = „ „ „ x_1, x_2, etc.

The "n" observations give n equations, as follows:—

$$
\begin{aligned}
b + x_1\, a - y_1 &= v_1 \\
b + x_2\, a - y_2 &= v_2 \\
&\cdots\cdots\cdots \\
b + x_n\, a - y_n &= v_n
\end{aligned}
\qquad (1)
$$

And forming the normal equations we have—

$$
\begin{aligned}
nb + [x]\, a - [y] &= 0 \\
[x]b + [x^2]a - [xy] &= 0
\end{aligned}
\qquad (2)
$$

From the first of these equations we have—

$$b = \frac{[y]}{n} - \frac{[x]}{n} a \tag{3}$$

But $\frac{[y]}{n} = y_0$, and $\frac{[x]}{n} = x_0$, $\therefore$ equation (3) becomes

$$b = y_0 - x_0 a \tag{4}$$

Substituting this value of b in equations (1) we have—

$$\begin{aligned}
(x_1 - x_0)\, a - (y_1 - y_0) &= v_1 \\
(x_2 - x_0)\, a - (y_2 - y_0) &= v_2 \\
&\cdots\cdots\cdots \\
(x_n - x_0)\, a - (y_n - y_0) &= v_n
\end{aligned} \tag{5}$$

Forming the normal equation in a from these equations we have—

$$[(x - x_0)^2]a - [(x - x_0)(y - y_0)] = 0 \tag{6}$$

Therefore

$$a = \frac{[(x - x_0)(y - y_0)]}{[(x - x_0)^2]} \tag{7}$$

[ ] Signifies summation.

Then having found the value of a in equation (7), by substituting it in equation (4), the value of b becomes known.

Graphic method of solution.

Equation (4) suggests a good method of graphically reducing the observations; for, from that equation, we see that the most probable line must pass through the point whose co-ordinates are x, y. If then we plot the point x, y, and draw a line through it in such a manner that the sum of the moments of the plotted points about that line and which cause it to rotate about the point x y shall be zero, then we have located graphically the position of the most probable line. In other words, plot the corresponding values of x and y on co-ordinate paper, and draw the most probable straight line through the points; then the tangent of the angle this makes with the axis of x is a, and the intercept on the axis of y is b. The graphical solution is a valuable check upon the numerical reduction, and should precede it.

The following example, taken from the records, is an illustration of the application of the numerical method for reduction of the equation :—

W. G. PRICE, *Observer.*

Reduction of Observations for rating meter, taken at Paducah, June 21st, 1882.

No.	r.	t.	$x=\frac{r}{t}$	y.	$x-x_0$	$y-y_0$	$(x-x_0)^2$	$(x-x_0)(y-y_0)$	Remarks.
1	100	53	1·886	3 774	+ 0 117	+ 0 245	+ 0·014	+ 0 029	Observations made with meter on a vertical iron rod 5 ft. in front of bow of skiff in pond. Length of base 200 ft.
2	101	44	2 295	4·544	+ 0 526	+ 1 015	+ 0 277	+ 0 534	
3	101	41	2 464	4 878	+ 0 695	+ 1·349	+ 0 483	+ 0·938	
4	96	124	0·774	1 613	- 0·995	- 1·916	+ 0 990	+ 1 906	
5	94	152	0 618	1·316	- 1·151	- 2·213	+ 1·325	+ 2 548	
6	90	193	0·466	1 036	- 1·303	- 2 493	+ 1·697	+ 3·249	
7	91	181	0 503	1 105	- 1 266	- 2·424	+ 1·603	+ 3·069	
8	103	28	3 678	7 142	+ 1·909	+ 3·613	+ 3·644	+ 6·903	
9	100	53	1·886	3·774	+ 0·117	+ 0·245	+ 0 014	+ 0·029	
10	98	73	1·342	2·740	- 0·427	- 0 789	+ 0 182	+ 0·337	
11	103	29	3·552	6·896	+ 1·783	+ 3·367	+ 3 178	+ 6·002	
Totals	...	19 464	38·818	...			+ 13·407	+ 25·544	
		$x_0=1$ 769	$y_0=3·529$	...					

Normal Equations.

$$b + 1·769\,a - 3·529 = 0$$
$$13·407\,a - 25·544 = 0$$

Hence $a = 1·9053$, and $b = 0·1590$

Equation of Rating.

$$y = 1·9053\,x + 0·1590.$$

Final reduction of discharge observations.

The calculations made at head-quarters, for the final computation and tabulation of discharges, consist of the following :—

Checking field calculation of reduction of rating observations.

Checking computation of discharge.

Computing datum areas.

Finally recording results.

The present custom is for the chief of the gauging party to submit his field book, his reduction of rating, and daily measurement of discharge properly computed as per computation sheet, see pages 42 to 44.

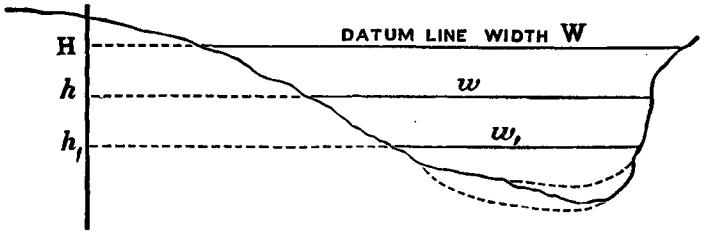
These sheets are checked and corrected if necessary, the corrections for obliquity of flow being made according to results of float observation taken for this purpose when locating the discharge cross section and subsequently every few days.

The field book has six columns showing the following :—Meter station (No. 15, 15¼—16, &c.); depth of sounding; time or duration of run (generally 200 or 300 seconds); registrations (first, last and difference); in fact all the data required by the computation sheet.

Computation of Discharge.—For this the partial areas are multiplied by the corresponding number of meter registrations, and the sum of the products, after being reduced to registrations per second, is multiplied by the co-efficient *a*. To this product is added the total area multiplied by the constant *b*; and the result obtained, when the current meters are run at six-tenths depth, gives the total discharge of the cross section. If, however, the general direction of the current varies more than 10 degrees from the perpendicular on the cross section a correction on this account is made in the final results. The mean velocity is deduced by dividing the discharge by the water area.

The final computation given on pages 42 to 44 is of a day's actual observations taken on November 30th, 1897.

Datum Areas.—By selecting a datum line from which to calculate the areas below datum, a means is provided not only for watching changes occurring in the bed, *viz.* the scour and fill, but also of keeping a permanent record of such changes and of the bed levels for the days on which soundings are made.



The datum line should preferably be chosen at or above highest known stage of the river. (See marginal sketch.)

Let the width at height H be W.

If this is not on record from previous measurements, the banks above highest recorded stage should be surveyed and the necessary additions to the recorded widths be made to obtain W; or it may be measured by triangulation.

Let h and h_1 be heights of stages at which discharge observations have been made, and for which datum areas are to be computed. Let w and w_1 be widths in feet at heights h and h_1.

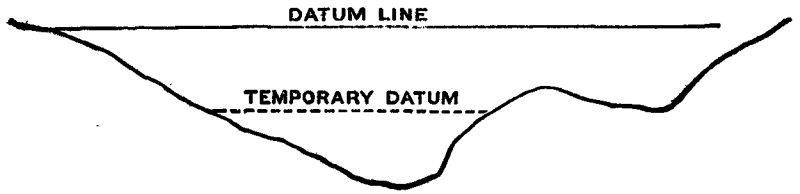
Let the area between the datum line and h be represented by A.

A is $= (H - h) \left\{\frac{W + w}{2}\right\}$

Then the datum area for height h = A + its water area.

The datum area for any less height h_1 = A + $(h - h_1) \left\{\frac{w + w_1}{2}\right\}$ + its water area.

Having once fixed the datum line for a discharge station, all datum areas and depths are referred to it. If necessary, as is occasionally the case in order to study low water stage datum areas, a temporary datum may be fixed at a lower level. (See sketch.) But to be comparable with other results, they must be also reduced to the common datum and be recorded in that shape.



The mean depths are simply areas divided by widths.

The results of discharges and datum area computations are compiled in tabulated form, of which a blank form is given on page 45.

Computation of Discharge of Mississippi River at Arkansas City, Ark; date, November 30th, 1897; gauge reading, 1·25 feet; width, 3055·5 feet; direction and force of wind, calm.

DISCHARGE NO. 10; METER WHEEL NO. 6.

Station.	Distance between s'dgs.	Soundings.	Area.		Registrations.	Product.		Remarks.
			Between s'dgs.	Partial.		Time in seconds.	Partial area × registrations	
	ft.	ft.	sq. ft.	sq. ft.				
1+4·5′=	W.E.R.B.	=0·0						
1¼	45′·5	19·3	439·1	1651·6	71	200	117263·6	
½	5Q	14·6	1212·5					
⅝	,,	39·3						
2	,,	40·0		7720·0	215	200	1659800·0	
¼	,,	40·4						

DISCHARGE NO. 10 ; METER WHEEL NO. 6.—(*Contd.*)

Station.	Distance between s'dgs.	Soundings.	Area.		Registrations.	Product.		Remarks.
			Between s'dgs.	Partial.		Time in seconds.	Partial area × registrations.	
	ft.	ft.	sq. ft.	sq. ft.				
½	,,	20·1	(½ actual sounding.)					
¾	,,	40·9						
3	,,	40·1		8080·0	189	200	1527120·0	
¼	,,	41·3						
½	,,	19·2						
¾	,,	35·2						
4	,,	32·5		6512·5	480	200	3126000·0	
¼	,,	30·7						
½	,,	12·65						
¾	,,	20·9						
5	,,	20·0		3805·0	551	200	2096555·0	
¼	,,	15·0						
½	,,	7·55						
¾	,,	14·8						
6	,,	13·7		2895·0	470	200	1360650·0	
¼	,,	14·5						
½	,,	7·35						
¾	,,	14·5						
7	,,	14·3		2867·5	398	200	1141265·0	
¼	,,	14·2						
½	,,	7·0						
¾	,,	13·8						
8	,,	13·7		2742·5	384	200	1053120·0	
¼	,,	13·7						
½	,,	6·65						
¾	,,	13·2						
9	,,	13·2		2640·0	430	200	1135200·0	
¼	,,	13·1						
½	,,	6·65						
¾	,,	13·1						
10	,,	15·1		2962·5	387	200	1146487·5	
¼	,,	16·6						

DISCHARGE NO. 10; METER WHEEL NO. 6.—(*Contd.*)

Station.	Distance between s'dgs.	Soundings.	Area.		Registrations.	Product.		Remarks.
			Between s'dgs.	Partial.		Time in seconds.	Partial area × registrations.	
	ft.	ft.	sq. ft.	sq. ft.				
½	ft.	7·8						
¾	,,	18·2						
11	,,	19·9		3657·5	412	200	1506890·0	
¼	,,	18·2						
½	,,	9·05						
¾	,,	17·1						
12	,,	17·0		3457·5	432	200	1493640·0	
¼	,,	17·4						
½	,,	8·6						
¾	,,	16·2						
13	,,	15·8		3202·5	409	200	1309822·5	
¼	,,	16·3						
½	,,	7·15						
¾	,,	14·2						
14	,,	13·2		2610·0	406	200	1059660·0	
¼	,,	12·2						
½	,,	5·45						
¾	,,	10·4						
15	,,	9·3		2207·5	287	200	633552·5	
¼	,,	8·6						
½	,,	7·9						
¾	,,	2·5						
16	,,	3·6	215·0	320·0	147	200	47040·0	
+25′	25′	2·0	70·0	57331·6		200	20414066·1	
	35′						102070·3 = Area × x.	
+60′ =	W.E.L.B.	0·0	35·0					
					Area × x × a =	116373·4		
	Constant	a	=1·14013		Area × b =	24062·0		
						140435·4	When velocity in feet per sec. =2·385.	
	,,	b	=0·4197					
						3721·6	Correction for direction of flow.	
			Total Discharge in		cu. ft. per sec. =	136713·8		

W. E. R. B. means water's edge right bank.

Results of Discharge Observations, *River,*

Date.	Gauges.			Cross Section of Discharge.						Scour or fill.	Mean velocity per second.	Discharge per second.	Discharge over bank per second.	Total discharge of river per second.	Method.	No. of Vel. Sta's.	No. of S'dgs.	Direction and force of wind.
				Area.		Depth.			Width.									
		Local.	Rise or fall in preceding 24 hours.	Water.	Below datum.	Mean.	Mean datum.	Maximum.										
	Feet.	Feet.	Feet.	Sqr. ft.	Sqr. ft.	Feet.	Feet.	Feet.	Feet.	Square feet.	Feet.	Cubic feet.	Cubic feet.	Cubic feet.				

A plan of the Arkansas City discharge station showing method there adopted in locating sounding stations by range poles is also attached. It will be noticed that the methods adopted on either side of the river are different. That shown with range poles on the river side of the pivot point is generally preferable, but in some cases where ground is not suitable for this method the poles are fixed beyond the pivot point as shown.

Map No. VII

PLAT OF ARKANSAS CITY DISCHARGE STATION.

SHOWING POSITION OF STATIONS, RANGE SIGNALS AND HUBS.
FOR LOW WATER DISCHARGE OBSERVATIONS.

MADE UNDER THE DIRECTION
OF
CAPT. H. E. WATERMAN, CORPS OF ENGINEERS, U.S.A.
SECRETARY MISSISSIPPI RIVER COM.
BY
EUGENE L. HARMAN, U. S. SURVEYOR,
U. S. STR. SEARCH.
LOW WATER DISCHARGE,—NOV. 1897.

SCALE OF FEET.

200 100 0 200 400 600 800

DISTANCES

A TO B —	3006.52	B TO TOP R.B. —	285.4
B " PIV.I —	1818.67	C " " L.B. —	20.0 APPROX.
B " C —	3761.90	D " PIV.3 —	34.0
C " D —	1389.67	E " " 2 —	75.0
C " E —	395.58	B " H' —	226.2

ANGLES

AT A	BETWEEN	B	AND	C	— 49° 12' 23"
" B	"	A	"	C	— 93° 33' 43"
" B	"	A	"	PIV.I.	— 3° 38' 35"
" C	"	A	"	B	— 37° 13' 54"
" C	"	B	"	D	— 88° 59' 50"

BASE LINE

PIVOT No 1

PIVOT No 3

PIVOT No 2

RIVER

TOP OF BANK

TOP OF BANK

LITH. THOMAS, SYMS & CO. BALTIMORE.

SEDIMENT OBSERVATION.

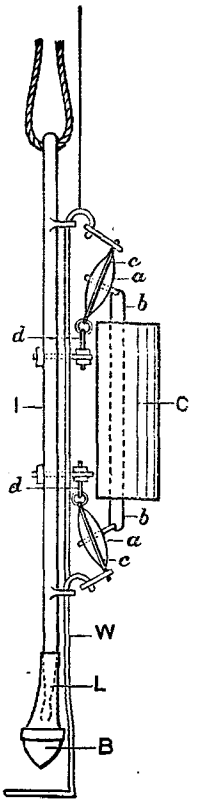
THE sediment carried in suspension in silt-bearing rivers may be divided into two general classes, (1) that in continuous suspension, such as fine particles of clay and mud of nearly the same weight as water, the deposition of which is prevented by any slight disturbance or eddying motion, and (2) sand and heavier matters held in discontinuous suspension according to the velocity and conditions of the current. The latter are picked up, carried on, dropped and rolled along the bottom as sand waves, or disposed more or less permanently, according to the condition of the channel and the stage of the water flowing through it.

The sediment continuously held in suspension is really of little importance to the Engineer, but the quantity liable to transportation, spoken of above as in discontinuous suspension, is of considerable importance. It is this material which makes up the sand bars, and which the Engineer uses, with the assistance of nature, to form contraction works behind dikes.

Measurement.

The measurement of the sediment may be divided into two operations; (1) obtaining the samples of water, (2) settling, filtering, and weighing out the sediment.

In order to obtain a correct average for a cross section, or on a vertical of the cross section, it is necessary to take samples at different depths. For this a special apparatus or silt bottle is required. Mr. Johnson, Assistant Engineer, designed an apparatus for collecting samples of water, which was used successfully at Helena in 1879. It is shown in the marginal sketch, next page, and is thus described by the designer: C is a galvanized iron cup, I an iron bar one inch square, L a mass of lead moulded on the bar, B the bottom cup which brings to the surface the specimen of the bottom, W the springing wire by which the lids a, a, are released and drawn together by rubber bands b, b, when the apparatus strikes the bottom or when the wire is pulled by an auxiliary cord from above; d, d, are adjustable hinges



allowing a tight joint on the rubber packing discs c, c, when the lids are closed.

In descending the lids are open and the water in the vessel C is always a fair sample of the water surrounding the apparatus. When the lids are closed, the sample is brought securely to the surface. The vessel when closed should be practically water tight.

Great care is necessary in taking the sample volume. It cannot be poured off even after violent shaking, for the heavy sand falls rapidly to the bottom. It should be drawn from the vessel by an aperture in its side. The sample is set aside to settle in a labelled bottle, and then the clear water, after settlement, may be syphoned off and the residue filtered through fine filter paper. The filter paper containing the sediment and a duplicate paper of the same weight are then dried in an oven at a temperature of about 150 degrees F.; and when quite dry the difference in weights is taken on a balance, this difference being the weight of the sediment which was contained in the sample of water.

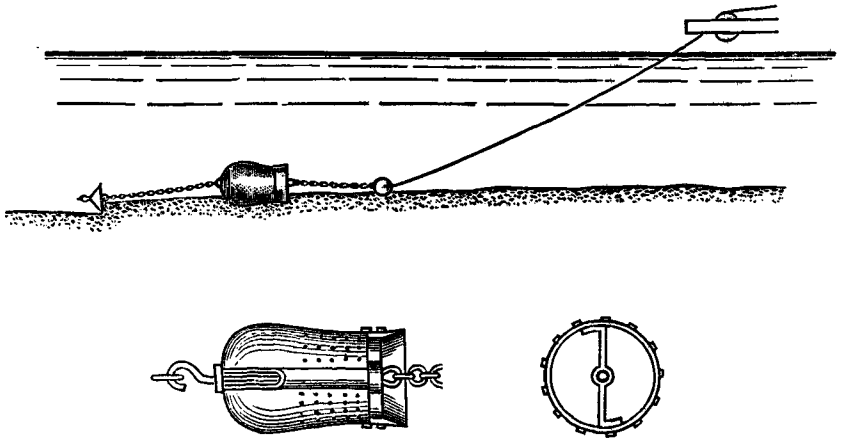
In the same year, namely 1879, a long series of careful observations was also made on the Missouri and Upper Mississippi Rivers of the amount of sediment carried in suspension. A greater nicety of methods was aimed at, and a special silt bottle was designed to bring up a pair of samples of the cubic contents required, *viz.*, 2 ounces each, direct from the depth of which the sample was wanted, thus eliminating the difficulty of drawing off from a large receptacle a small correct average sample. These observations are said to have since proved most useful. The instruments used are described in the Chief Engineer's Report of 1887, Appendix E, of which a synopsis is given below.

No sediment observations have been made of late years on the Lower Mississippi, but the writer found, after enquiry in the Secretary's office, a slit bottle of the pattern formerly used.

Silt observations at St. Charles.

For obtaining large samples of the river bed a sheet iron dredge bucket was used, of which a sketch is given next page. Across the top of the bucket is an iron bar, with its ends bent at right angles and rivetted to the side of the

bucket. Above this bar, and also rivetted to the bucket, is an annular lip with bevelled edge to facilitate entrance of the bucket into the river bed. Between the cross bar and bottom of the bucket is a



sleeve through which passess an iron rod with an eye at the upper end and a hook at the lower. A lead ball is attached to the leading chain to keep the pull on the bucket horizontal, and an anchor is provided in rear of the bucket to prevent the bottom of the bucket from rising as the lip enters the river bottom.

In the earlier experiments a slip bottle, similar in design to that used on board H. M. S. *Challenger*, was tried; but experience showed that the sediment had partially settled when the bottle reached the surface and that mechanical agitation did not restore the normal distribution, so as to render the small samples trustworthy. To obviate this difficulty a special silt bottle was designed.

The St. Charles silt bottle.

This bottle, which may be called the St. Charles silt bottle, is rather an elaborate one. It is of brass, and has to be specially made. A plan of it is given on next plate, and its description is as follows:—

It has two receptacles of 2 fluid ounces each, each receptacle consisting of two parts, (1) a hollow cylinder with four short horns 90 degrees apart projecting radially from its outer edge and outer surface, and (2) a piston of the same length as the cylinder, cut out by two rectangular slots at right angles, in such a manner that the piston becomes two disks separated by four posts. From the lower

surface of the piston projects a cylindrical pin, with a turned neck by which connection is made with the other parts of the machine.

The closing mechanism consists of a hollow cylindrical post reduced at the upper end, within which is fitted a piston head having a stem running through the reduced opening at the upper end and attached to the cross head and grip handle by a through key. Between the piston head and the upper end of the cylinder is a spiral spring, and through the piston head at right angles to the axis of the post a tumbler pin is driven passing through opposite and vertical slots, cut through the walls of the hollow post, and projecting sufficiently to be caught by two sear-hooks when the piston is raised.

These sear-hooks are connected by a swivel pin and ring to the line by which the machine is raised or lowered.

Parallel to the centre post and supported from it by a lug at each end is a pipe with a bore four or five times the diameter of the standing wire. An open slit is cut through both lugs and pipe sufficiently large to allow the standing wire to be introduced laterally, after which, by revolving the pipe part of a turn, the solid parts of the lugs cover the open parts of the pipe and prevent the possibility of disengagement.

At the lower end of the post there are two radial disc plates, and at the upper end two radial arms, each carrying a perforated box at its extremity, the centre of the perforation being directly over the centre of the disc below. Through each perforation or hole passes a vertically sliding rod, having at its lower end a four-armed spider and at its upper end a simple swivel connection with the cross head.

In the outside of the circumference of the lower disc plates radial slots are cut of a breadth just equal to the diameter of the turned neck in the bottle, and of a length just sufficient to allow the centre of the bottle, when the neck is slid into the slot, to correspond with the centre of the disc plate and the vertically sliding rod.

The bottle is prevented from sliding out by a latch spring, which is automatically compressed when the bottle is slid into place, and is easily depressed by the little finger when the bottle is to be removed.

The machine was used by lowering it gently upon a standing line of No. 12 wire and, when at the proper depth, giving a sharp jerk to the lowering rope which tripped the bells, and the machine was then drawn up.

FRONT ELEVATION

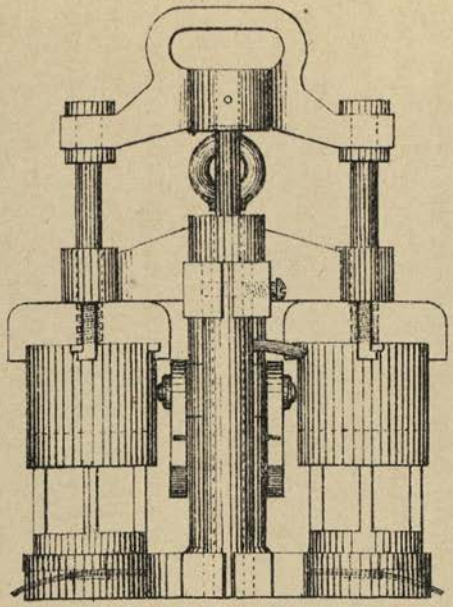


Fig 1.

SECTION A. B.

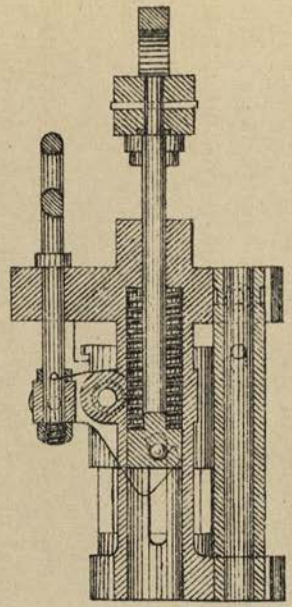


Fig 2.

SIDE ELEVATION

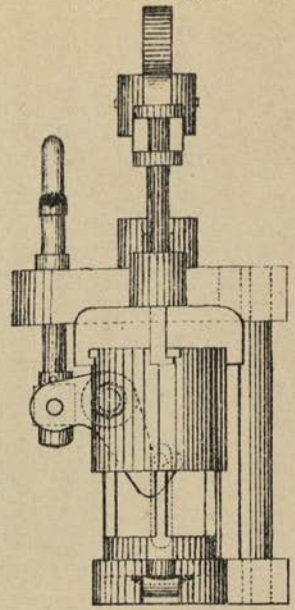


Fig 3.

PLAN

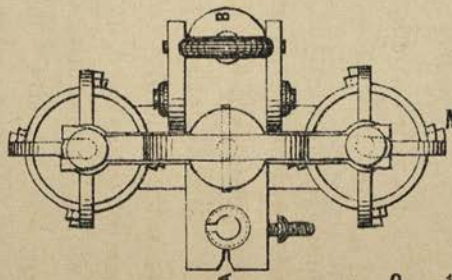


Fig 4.

DOUBLE SLIPBOTTLE

USED IN

SEDIMENT OBSERVATIONS

ON

MISSISSIPPI MISSOURI AND ARKANSAS RIVERS

1879

0 1 2 3 4 5 6 7 8 9 10 11

PLAN OF BOTTOM.

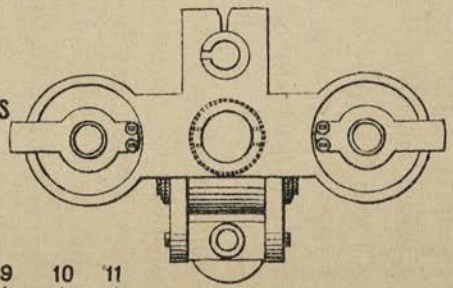


Fig 5.

LITHO THACKER, SPINK & CO, CALCUTTA

Obtaining samples of water.

Samples of water were taken at eight locations across the river and at three points for each location, *viz.*, at surface, mid-depth, and one foot above bottom.

The contents of one receptacle of each sample was poured into a pint bottle for an average surface sample, and the same for mid-depth and bottom, giving each day three pint bottles in what were called the horizontal combinations. The remaining samples were combined vertically at each location in the earlier experiments, but latterly were omitted as they were not found of any special interest.

In treating the samples the bottles were uncorked and the clear water carefully poured off into a measuring tube, graduated to cubic centimetres, and the volume noted. It was then poured back into the bottle, and the tube rinsed out with filtered water, which was also poured into the bottle. The corks were then replaced and the bottles violently shaken, after which the contents were poured upon the filters, the bottles rinsed with filtered water and the product added to the proper filters. The standards were put into the funnels and treated with the same amount of filtered water.

While the papers were still wet they were transferred to the drying box, which had been previously heated to the proper temperature, when one of the standards was placed in the hottest and the other in the coolest part of the box. The two standards were taken out from time to time and compared in the scales. At first the one in the hottest position would weigh the less but their weights gradually approached each other until they finally balanced; after which they were left in the box a few minutes in order to secure the same hydrometric state in all the papers. When taken from the drying box the papers were placed on a rack beside the weighing case, one of the standards being placed in the centre of the group and the other in the scale pan. As soon as the papers were cool the standard on the rack was counterbalanced against the one in the case and the difference noted. The papers were then compared with the standard in the case and this difference noted. By this process the papers were compared with the standards which remained in the rack with them.

In this way the sediment in millogrammes per pint was determined.

Method of computation.

The mean of the surface, mid-depth and foot from bottom combinations, in other words, the mean of the sediment in the horizontal combinations, was taken as the aver-

age sediment per pint of the cross section. The total sediment carried was thus computed on the assumption that there is a mean sediment per cubic foot of water which represents the saturation of the discharge with sediment at that time. This method may perhaps be questioned, since it is known that there is a considerable difference of discharge in different parts of the cross section. It is thought, however, that the sediment data in the main justifies the above method of computation, except perhaps at periods of small mean sediment where minor errors would be immaterial.

The observations were taken continuously from February the 1st to October the 1st, 1879, at St. Charles, Mo., and are tabulated with the discharge measurements of the river in the following form:

Date.	Gauge Reading.	Sediment in Milligrammes per pint.						Mean Sediment in grains per cubic foot.		Discharge in cubic feet per second.		Total Sediment.	
		Horizontal Combination.				Vertical Combination Mean.	Resulting Mean.	Observed.	Interpolated.	Observed.	Interpolated.	Per second in Kilograms.	Per day in cubic yards.
		Surface.	Mid depth.	Foot from bottom.	Mean								
May 2	11·52	1041	1441	1487	1323		1323	79·17		66,220		5242·9	369,880
„ 3	11·37	1316	1364	1536	1405		1405	8408			63,000	5297·1	374,565
„ 4	11·32								74·20		61,700	4578 1	323,726
&c.	&c.												

A diagram is also given showing the total sediment carried per second throughout the period of observation. This is plotted below a diagram of the discharges of the river for the same period.

A casual analysis of the tabulated results shows that the quantity of sediment carried by the Missouri varies from about 1/3000th part of its weight in low water to as much as 1/120 in high water.

A number of tests taken for the specific gravity of the sediment gave an average of 1·6.

Caving Bank in Kemps Bend, showing destruction of levee, Dec. 1898.

CHAPTER III.

EROSION OF BANKS.

In 1891 an inspection was made of the condition of the permanent survey marks, and at the same time, at Mr. Ockerson's suggestion, the bank line and the bends of the river were resurveyed. Blue prints have been made showing the bank lines of 1891 plotted on the charts of the original survey made by the Commission ten or twelve years previously in this length of river, *viz.*, from Cairo to Donaldsonville.

These blue prints are, in the writer's opinion, of considerable value, because they faithfully record the final changes which have occurred in this long length of 885 miles of the river during the period between the two surveys. They are so instructive, especially as regards the shape, direction and movement of erosion or caving on bends, that the writer applied for, and, through the kindness of the Commission, has secured a set of them which are attached as accompaniments to these notes (not printed).

Definitions: Caving, Slough, Slump.

Though it is not proposed in this note to deal at all with bank protection or the measures adopted for the prevention of caving, it may be useful to briefly describe what the term "Caving" means, as applied on the Mississippi River.

"Caving" includes erosion or abrasion, slips or sloughs of all kinds and slumps. The word might, perhaps, be correctly applied to either of the latter, as in each there is a kind of caving or sliding of the bank in consequence of its being undermined. It has, however, by usage, become much more comprehensive and expresses destruction or wearing away of the bank of the river from any cause, whether due to the violence of the direct attack of the current on a bank, as at a crossing, or to the falling in of the concave side of a bend of which the curvature is changing.

A "Slough," pronounced "sluff" is a slip caused by the undermining of the foot of the bank or slope, assisted by the action of drainage water through the bank itself.

"Slough," another word pronounced "slew" is commonly applied in the Mississippi Valley to old river channels, and correspondents to "Dhand" on the Indus.

A "Slump" may be described as a sudden slip or collapse of the bank, generally in a vertical direction, probably due to the substratum being washed out or having become unable to bear the weight above it. In many cases the river bank for a distance of from 50 to 250 feet back suddenly drops down vertically, 10 to 30 feet in height, taking with it trees, which are thus temporarily transplanted to a lower level along the face of the river. How long they retain this position depends on the violence of the current and on the character of the soil in which the roots are embedded, but the slump is gradually disintegrated and probably disappears on the next rise in stage of the river. The sound of the word itself conveys, with American significance, its meaning and is very expressive of the sudden vertical collapse of a portion of the bank or river face.

Kinds of Caving.

The description of caving which occurs at any point and its rate of progress and extent depend on many circumstances: on the material of which the bank is composed and its drainage, the curvature of the bank and its general direction with reference to the line of attack, the velocity of the water, position and depth of the channel and the stage of the river.

The Mississippi Engineers generally agree in saying that all kinds of caving are more active, as a rule, on a falling stage of the river, and most active during a sudden fall after a prolonged medium stage. This is particularly the case in bends. The channels are probably deepened during the high stage; then on the fall of the water the lighter materials of some of the intermediate strata wash out, and the bank, having been undermined at its toe, slips or caves in. In some cases, however, particularly where there is a deep firm stratum of material on the face of a long bend, erosion may continue fairly steadily, though not at the same part of the curvature, the point of attack or the active erosion oscillating up and down stream

with the rise and fall in stage of the river. This longitudinal oscillation is no doubt due to the alteration in direction of the crossing at different stages of the river.

A study of the blue prints has helped to elucidate some of these points, especially when assisted with Mr. Ockerson's remarks. A brief report on the subject of this re-survey was published in the Annual Report of the Mississippi River Commission of 1892, but Mr. Ockerson, having made careful notes on the ground of the nature of the banks, &c., in November of that year, thought the subject, as further elaborated, of sufficient interest for a paper before the American Society of Civil Engineers. This was read in June 1893. Finding the writer particularly interested in the results shown by the re-survey, Mr. Ockerson kindly placed the only available copy of his paper at the writer's disposal, with permission to quote from it.

Mr Ockerson premises his paper by remarking: "It is believed that these surveys offer the first opportunity of an accurate determination of the amount of erosion, and may throw some light on the conditions affecting this amount."

He expresses regret that the importance of establishing fixed points did not occur to Humphreys and Abbot during their extended investigations of the river, for if they had done so we would now have a much broader base for our study, and more well determined constants to aid in the solution of the problems of regulation and control of this great river. "We have only a period of about ten years during which the regimen of the river has been carefully noted and recorded, and during that time many important principles have been worked out, and facts have taken the place of theories."

Lateral oscillation of the river.

In order to obtain some idea of the lateral oscillation of the stream during a long period, he took the oldest map procurable, one dated 1770, and reduced it and the first charts of accurate surveys made by the Mississippi River Commission to the same scale, and compared them. Though it is not claimed that the old map will bear the tests of rigid measurement, yet he states "it is readily seen that the work is entitled to the credit of being a careful reconnaissance of high grade in which the important features were very well sketched."

The striking features of his comparison are the remarkable stability

of the larger islands, the very marked similarity of the bends, the similarity in location of cut-offs which have been repeated in modern times over nearly the same ground as in former years, and generally, the narrow limits within which the lateral oscillation of the stream is confined.

He remarks that in his early reports to the Mississippi River Commission, he "called attention to the pertinacity with which deep indentations and projecting points maintained their identity, although the entire bank line receded several hundred feet. This being true, it may be urged that the similarity of the bends and apparent stability of the islands furnished little or no proof of the varying movement of the river, that is, large islands might move bodily down stream or laterally for long distances. Furthermore it is known that the heads of islands are eroded and accretions are added at their lower ends. It is, however, evident that the rate of this movement is not as great as is generally believed."

He speaks of the mute evidence of the huge trees of the forests bordering the river and covering many of its islands, which have withstood the floods and encroachments of the river for several scores of years, clearly proving that the lateral oscillations of the river are confined within comparatively narrow bounds even when the unit of time far exceeds the memory of the oldest inhabitants.

He further remarks that the data for comparison of geological periods after the alluvial valleys ceased to be an arm of the sea have never been obtained, and perhaps never will be; that, therefore, we must be contented with the materials which the maps of earlier explorers give us, with the satisfaction of knowing that future engineers will have convenient and definite means of studying the changes which occur in the regimen of the river.

Extent of erosion.

Attached to his paper are small scale reproductions of the blue print maps, the study of which is recommended to obtain a general idea of the nature and extent of the erosion.

Mr. Ockerson explains that "the term erosion rather implies a steady wearing away. In some cases this condition is fulfilled, but generally, where changes are rapid, the process is entirely different. No great amount of caving occurs at high water. The period of great activity is generally found to be during the falling stage, from a little below the medium stage down."

He points out a particular feature in the development of a cut-off, quite contrary to popular ideas, which, because of his long and intimate experience of the Mississippi while in charge of its survey, is worth recording here as the statement of an authority on this point. He says: "The neck of land may be quite narrow with a long distance around the bend; consequently the slope across it is much greater than the general slope of the stream. The natural supposition then would be that the cut-off would be due to scour from the top. This, however, is rarely the case, and the opposite is more frequently true. That is, the neck is actually built up by deposit. Consequently the seemingly frail barriers stand for many years and finally break through in a few hours without warning. More than likely the usual process of undermining, washing out a layer of sand, is the immediate cause of the break. When the surface is once thus broken the excessive slope in an overflowing stage plays an important part in hastening the demolition of the barriers."

Cases are mentioned where the banks of apparently homogeneous sand and silt crumble away rapidly and continuously, the caving face being nearly vertical. At other places where banks are of clay, in general all of the river below Baton Rouge, there is comparatively little caving. Old Town bend, 325 miles from Cairo, is mentioned as having been always conspicuous for the great amount of timber standing in the water, several hundred feet from the banks proper. Large areas slump down, cracking and breaking up as they go, but the trees remain standing. Then he tells of cracks which appeared 250 feet back from the river face and extended 1,600 feet in length through New Orleans in 1891, the area gradually settled 5 to 10 feet, but further movement then apparently ceased. Railroad tracks were levelled up and the levees repaired, and no further damage has been done. Borings in the vicinity show a stiff clay for fifty feet depth overlying a stratum of sand of about the same depth.

The Lower Mississippi is characterized by a succession of long sweeping bends, with short straight reaches between them. The channel lies along one side for a distance and then "crosses" over to the other, eroding the banks alternately on either side of the river. The channel from one side of the river to the other is known as the "crossing," and it is here that the bars form which obstruct navigation.

Estimate of Erosion.

The amount of erosion in the resurveyed length of the river is calculated, and tabulated in the form shown below :—

Bank.	Distance from Cairo.	Length in yards.	Average depth in yards.	Caving per annum.		Curvature.		Percentage cultivated.	Character of Banks.
				Area in 1,000 sq. yds.	Volume in 1,000 cub. yds.	Radius in miles.	Degrees.		
Left	740·8	1,550	15	26	382	...	...	0	Sandy.
„	745·8	10,200	26 9	273	7,316	2·75	100	30	Sand and clay.
Right, &c.	749·6 &c.	5,220	31·4	110	3,449	6·00	30	20	Sand.

And the whole is summed up as under :—

Total caving per annum, left bank, 430 miles, 18,879,000 sq. yds.
„ „ „ „ right bank, 469 „ 19,130,000 „
„ „ „ „ both banks, 916 „ 39,016,000 „
Total average caving per mile of river per annum 44,186 „
„ „ „ „ „ „ „ R. bank 21,725 „
„ „ „ „ „ „ „ L. bank 21,391 „
„ „ „ of caving bank „ R. bank 40,928 „
„ „ „ „ „ „ „ L. bank 43,904 „

The area of erosion was taken out by planimeter from the maps of the old survey, scale 1 to 20,000, on which the new survey was plotted. The annual rate of erosion for each area was obtained by dividing the total amount of erosion by the number of years between the two surveys of that length of the river; this method assumes the rate of caving to have been constant, which, while not absolutely true, answers for the purpose of comparison. The height of banks was derived from soundings at known stages and known elevations of the banks, both being shown on the detailed maps. Curvature was taken by drawing the curve which best filled the general trend of the river, and then measuring the radius and angle included between the limiting radii.

An examination of the table shows that, in the whole length of 885 miles of river, there are 17 bends with radius of one mile or less, 25 with radius from 1 to 1½ miles, 27 with radius of 1½ to 2 miles, 38 with radius of 2 to 3 miles, and 99 with radius over 3 miles.

The bends of one mile or less radius are mostly in the lower reaches of the river, 9 being 800 miles or more below Cairo. It might be thought, at first sight, that the greatest erosion would occur in the lengths of the river having bends of sharpest curvature. This is however not the case.

To assist in analysing results Mr. Ockerson prepared from the above statement a graphic representation, of which a copy is given next page, showing the rate of caving per annum on each caving area, plotted as elongated triangles at right angles to each bank of the river, the apex of each giving the rate of caving in square yards per annum per mile of the length.

Portions of the river which have been leveed are shown on the diagram, and the relative curvature of the more important bends are also shown by lines plotted at right angles to the direction of the river on the right bank. These lines express the ratio of the curve and its chord.

Conclusions of Analysis of Maps and Diagram.

The following are, in effect, the conclusions arrived at by Mr. Ockerson by analysis of results obtained from the survey :—

From Cairo down to 510 miles below it the erosion is tolerably uniform. Though there are some areas of considerable erosion they are all far less in amount than in the next reach or stretch of river. In this length there are ten cut-off lakes, or an average of one for every 51 miles of river.

The maximum rate of erosion occurs between limits of 510 and 660 miles from Cairo ; it is here far in excess of that of any other reach. At 620 miles on the left bank, at Newton's Bend, it amounts to 224,000 square yards per mile per annum.

The left bank levee system ends at 575 miles below Cairo, near the lower end of the Yazoo basin. South of this point the hills are close to the river bank, which is not leveed until Baton Rouge is reached, 830 miles from Cairo. The right bank levee system begins 425 miles below Cairo, and extends down to 735 miles. It is seen then that the area of greatest caving coincides with the leveed portion of the river in the middle reach. Mr. Ockerson remarks that " this coincidence suggests that there is some intimate relation between the two." He draws attention to the fact, however, that the comparison made gives no clue to the rate of erosion before the levee period.

It must be mentioned here that south from Baton Rouge the levees are intact on both sides of the river, and they stand immediately on its banks, which are generally 100 feet or more in height, yet caving is comparatively light. The caving diminishes gradually too as the Gulf is approached.

Then, speaking of other factors which undoubtedly influence erosion, he points out that the cut-off which occurred in 1884 at Coles Point, 665 miles below Cairo, shortened the distance between Vicksburg and Natchez about 12 miles, or about 12 per cent. of the length. The increase of slope in this length must have had a marked influence on bank erosion there. On the other hand, that erosion has been active in this region for a much longer period than the levees have been in use is abundantly shown by the nine cut-off lakes marking the former bed of the stream, an average of 1 to every 17 miles of river.

Moreover, as previously stated, it is generally acknowledged that active erosion is greatest at or below medium stage, that is when the river is within its banks. Mr. Ockerson puts the question "How then can the levees affect or influence the amount of bank erosion?" His analysis does not supply an answer.

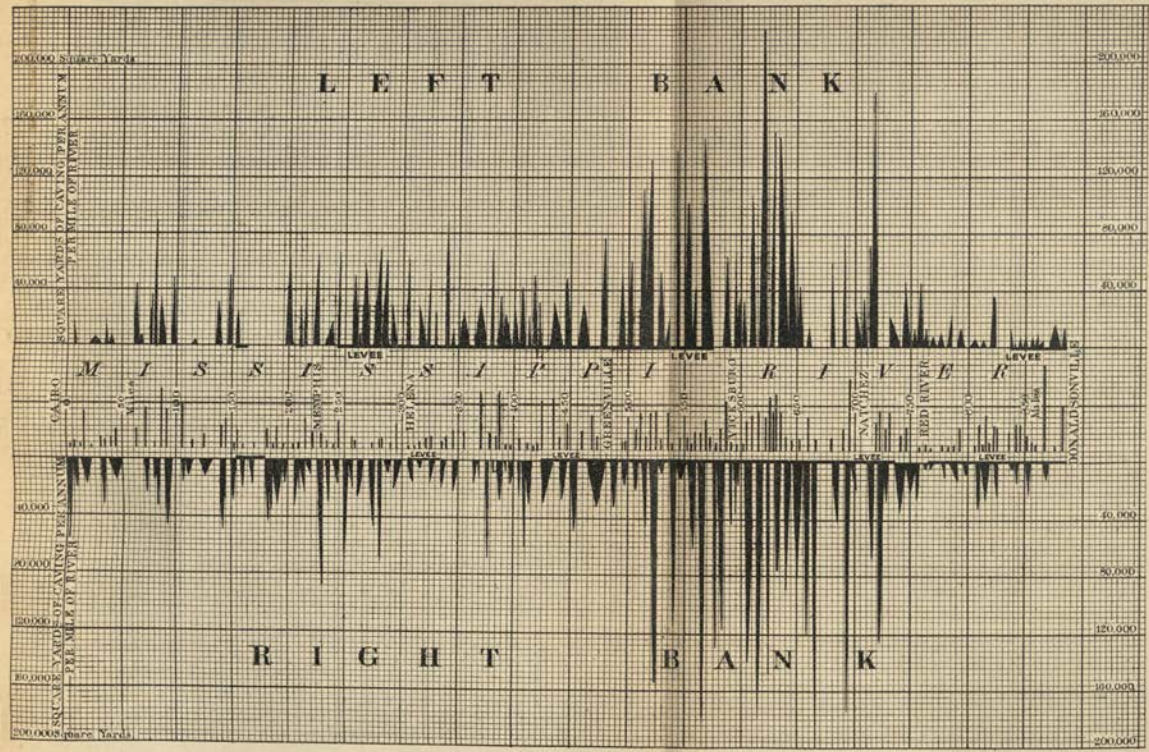
Effect of slope on erosion.

It was thought by the writer that a study of the surface slope would assist in explaining the excessive erosion on the Vicksburg reach. One would expect at first sight to find it there considerably greater than in the upper reaches where the erosion is so much less. That such is, however, not the case is shown by the following figures:—

Referring back to the general description of the valley, the slope of the river at average stage, from Cairo to Memphis, 230 miles, is given as ·403 feet per mile; and from Memphis (mile 230) to Vicksburg (mile 599) as ·353 feet per mile; while at maximum stage the slope of the 1897 flood from Cairo to Memphis was ·438 feet per mile, and from Memphis to Vicksburg was ·334 feet per mile.

Again considering short reaches in the vicinity of active erosion, Mr. Starling gives the slopes of *high water*, from 1888 to 1893, as follows:—From Arkansas City (mile 438) to Greenville (mile 478) slope of ·323 to ·340 feet per mile. From Greenville (mile 478) to Lake Providence (mile 542) ·322 to ·327 feet per mile. From Lake Providence (mile 542) to Vicksburg (mile 559) ·319 feet per mile.

Thus just above and on the reach of greatest activity of erosion



LITHO. BY THACKER, SPINK & CO. CALCUTTA.

the slope of average high water is from ·319 to ·327, while in the next reach above it is from ·323 to ·340 feet per mile.

An examination of the low water slope in short reaches from Cairo to Arkansas City for 1891 shows that, except between Cairo and New Madrid and from Helena to Sunflower Landing, altogether only 116 miles out of the whole length, the slope everywhere exceeded ·36, and in places was over ·5 feet per mile. At high water it varied from ·31 to ·486 feet per mile from Cairo to Sunflower Landing (mile 352); thence it decreased from that point to Arkansas City (mile 438) to ·27 feet per mile.

It may, therefore, apparently be correctly said, in general terms, that the slope of water surface through the reach of most active erosion is rather less, both at low and high stages of the river, than it is in the 500 miles above.

Mr. Ockerson does not discuss the influence of slope on the region of active erosion, but he suggests that "It is more than probable that the locality of active erosion is moving slowly, that perhaps the adjustment between the slope and momentum and the section of river bed and stability of river bank has been completed, and the proper equilibrium established at the lower end of the river; that these conditions of equilibrium are working upstream, preceded by an area of excessive activity, and leaving behind an ideal completed river." He says that "we should then expect to find, in the course of time, that the area of excessive erosion had moved upstream."

Definite conclusions by Mr. Ockerson.

On the following points, however, Mr. Ockerson speaks decisively.

(1) Excessive curvature and excessive erosion are rarely coincident. This is seen from a casual inspection of his statement of erosion.

(2) The rate of erosion is not hastened by cultivation of the banks. It has been argued that the roots of trees hold the soil together and help to prevent erosion. If the caving process was one of gradual disintegration this might be true, but undermining is the active agent, and it occurs far below the influence of roots. Mr. Ockerson says that "A careful investigation of all the bends fails to reveal any irregularity in erosion of alternating strips of timber and cultivation in a caving reach, and it is reasonable to

conclude that the character of the vegetation has little or nothing to do with the amount of erosion."

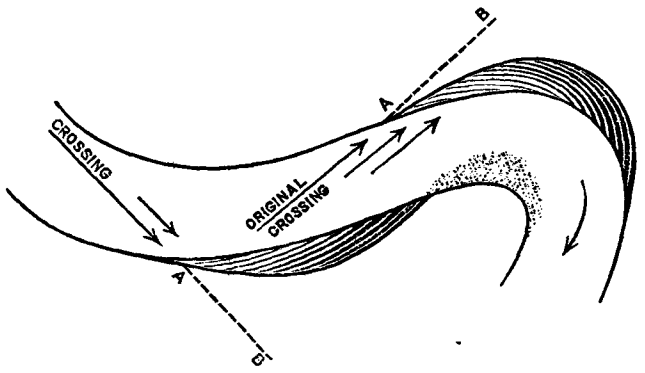
(3) "It very rarely happens that both banks cave in the same locality at the same time, and, as a general rule, it may be accepted as practically true that erosion on one bank is followed by an equivalent accretion on the other."

In summing up the totals of the tabulated statement it is seen that in 885 miles of river there are 916 miles of caving banks including islands. The average annual rate of caving per mile of river is about 9 acres; the average depth is 66 feet; and the volume of erosion per mile is 972,092 cubic yards. The average annual erosion from Cairo to Donaldsonville would amount to about 10 square miles 84 feet deep.

It is said that by sediment observations, the amount of solid matter in suspension passing New Orleans is computed at 10 square miles, 26·8 feet deep, or less than one-third of the amount of erosion. "The two-thirds and more not accounted for go to build up the bars which obstruct navigation and the points which follow the caving bends by accretion."

Further conclusions by the writer.

The writer thinks further and very important conclusions can be drawn from the study of these maps. They are: (1) that in general the direction of the movement or progress of caving in a bend is largely influenced by the direction of the channel crossing; (2) that the width of the eroded area increases as the erosion, or caving, progresses downstream, until the point of reversion is approached; and (3) that the concave curve of the bank left by the advancing erosive action is generally situated to the downstream side of the produced line of the crossing or line of approach of the first attack. This "downstream side" may be at any point of the compass, irrespective of the general direction of the



river. The movement of the erosion is dependent on the direction of the crossing, not on the general axis of the river.

The curved shade lines on the concave bends, in the marginal sketch, illustrate the movement of the erosion in a downstream direction with reference to *A B*, the produced line of the crossing. Many examples of this movement may be found on the maps. There are exceptions to it, but only a few that can apparently not be explained.

Of course these remarks only apply to reaches where the river is confined to one general channel. At or near tributaries, or outlets, there are disturbing factors which generally so alter the condition that the resulting eddying flow may cut all sorts of freaks. Again specially constructed dikes or revetment works along the banks may limit or modify the action of the river; and, in examining the maps, it is necessary to choose only fair examples to reduce any general conclusions from the recorded changes which have occurred between the two surveys.

Attention is particularly drawn to this point because, if a general rule can be deduced from the history of such movement, it should greatly assist in the location of a loop of a levee, or river embankment, the encroachment on which is being threatened at a caving bank of the river.

Mr. Ockerson has not remarked especially upon this point, yet that the progression of erosion along the concave bank is recognized by the Mississippi Engineers is clearly evidenced by remarks made by Mr. Starling, at a discussion on Mr. Coppee's paper on Bank Revetment, read before the American Society in 1896.

He says that "In the early application of bank protection care was taken to rest the upper end of the work under a bar or at a point where the bank was stationary, so that the revetment should not be flanked or taken in reverse by erosion above its commencement." He relates how this precaution was sometimes carried to excess, how by the time a mile or so of work had been completed, "perhaps half of it was rendered unnecessary by the advance downstream of the bar at its head." When Greenville was threatened in 1891, it was decided to depart from the ordinary method and begin at the lower end of the caving reach where there was the greatest necessity for immediate action. Over 6,000 lineal feet of mattress was laid from below upward. "It was feared there would be a very serious loss of

material at the upper end, but the apprehensions were not justified by the event." Next year over 4,000 feet were laid the same way with the same results. The success of these experiments induced the Mississippi Commission to proceed in the same manner at Lake Providence in 1895, and Mr. Starling says, " Doubtless this will be a well-recognized feature of practice in the future."

In other words, it may be said to be recognized that the movement of erosion is downstream, and that by working up to meet it a considerable amount of bank protection may be saved by the movement downstream of the destructive forces during the progress of the work.

If we could but anticipate, or locate, the probable movement of the more violent erosive forces it would enable us to effect considerable economy in bank protection works and in flood protection or levee works; in the latter, especially where it becomes necessary to retire the levee line and construct a new loop because of a threatened encroachment of the river.

The Mississippi Commission's description of caving.

Since writing the above note it has come to the writer's notice that incidentally the Mississippi Commission have recorded, in definite terms, a description of the movement or travel of caving, which may therefore be quoted as authoritative. The following is an extract from the report of a special Committee of the Commission, " on the general plan upon which shall be based the future recommendations of the Commission with regard to the improvement of the river," given in Volume VI of the Chief of Engineers' Report for 1896.

" The general shape of the river channel presents a series of groups or bends whose convexities are alternately turned in opposite directions. Against the concave side of these bends the current usually presses with force and the banks are eroded steadily, though at greatly varying rates. The water in passing from one bend to another usually spreads out in a fan-shaped mass, in such a manner as to enter the lower bend throughout the greater portion of its length. Following this concentration we find the erosion, as a general rule, least at the head and *greatest towards the foot of each bend.*

" It is, however, rarely continuous and uniform, but generally starts over short lengths of bank, forming pockets, *which work downstream* by erosion on their lower sides, thus removing ultimately a

swath of varying width; *this latter increasing as the cut progresses.* These cuts change the direction of flows sufficiently to affect the crossing into the next bend. This in turn changes the point of impact, and a new focus of erosion is started, which, in turn, affects the bend below and so on indefinitely.

They next state: "It is therefore apparent that this destructive effect must be stopped from above as *it always travels downstream, never the reverse.* (The italics are of the writer.)

"It is also well known that caving is rarely ever continuous throughout a bend, though successive caves, initiated as stated by changes above, may ultimately extend it over the entire bend, and it will appear like a continuous action when the results only of a long period of time are considered." For this reason it is added, "it is not believed that all caving banks will need protection, nor the entire length of concave bends."

CHAPTER IV

Levees or Protective Embankments—Lessons of the 1897 Flood—Levee Construction in 1898—Effects of Levees on the River Channel.

LEVEES OR PROTECTIVE EMBANKMENTS.

History.

PREVIOUS to the war the fronts of the different basins in the Central Valley were protected by lines of levees of weak profile and insufficient height. During the war the armies frequently cut the levee lines, and then the floods of 1862 to 1865 very generally destroyed the remains left by the troops. Spasmodic efforts were made by local authorities to repair their levees, but the flood of 1882 again devastated the whole country.

The United States Government then gave assistance in reconstructing the levee lines, and since that date, 1882, the work has been rigorously prosecuted by the General Government and by the State and Local Boards. At the present time it is recognized that there is no doubt of the ability of the Engineers to construct levees which will give thorough protection, if funds be granted sufficient to undertake the raising and enlargement of the whole system to such height as experience and investigation are showing to be necessary.

District Control.

As stated before, the levees, or river embankments, are not entirely under the control of the United States Corps Engineers, the responsibility being divided with the Local State Engineers, practically relatively to the allotments granted by Congress and the Local State Governments.

The first U. S. Corps District covers about 200 miles of river below Cairo, and includes the leveeing of the St. Francis Basin, a contemplated total length of about 220 miles of levees on the right bank of the river, of which about 130 have been constructed.

The second District, 118 miles long by river, includes two Levee sub-divisions, *viz.*, the White River Levees on the right bank, from miles 306 to 385, in which 64 miles have been built to protect

Raising a Levee with "Scrapers."

the White River Basin; and the Upper Yazoo Levees, on the left bank, which contains 124 miles of levees.

The third District, 220 miles by river, includes the Upper Tensas Levees, 173 miles in length on the right bank, and the Lower Yazoo Levees, 185 miles in length, covering about 216 miles of river, on the left bank.

The fourth District, which extends from about mile 600 below Cairo to the Passes, comprises the following Levee systems. On the right bank: the Lower Tensas Levees, a continuation of the Upper Tensas line, about 130 miles in length; the Atchafayala Levees, extending from the mouth of the Red River to Bayou Lafourche, also 130 miles long; the Lafourche Levees, which are continuous from Bayou Lafourche to New Orleans, a distance of 75 miles, and the Barataria Levees, south of New Orleans to the "Jump," a few miles above the Passes, 72 miles in length. On the left bank it includes the Pontchartrain Levees, which extend from Baton Rouge, 833 miles below Cairo, to New Orleans, a length of 125 miles, and the Lake Borgue Levees, which are continuous from New Orleans to Fort St. Phillip, opposite Fort Jackson, at mile 1,039, and have a length of 75 miles.

There are a few short lengths of levees below this point built by the land-owners as part of fence levees enclosing small tracts of cultivation. They are, however, of little importance and are not included in the lengths which are cared for by the State.

Summary of above.

Tabulating above figures of lengths, the distribution of the system of levees, from Cairo to the Passes, is as shown below :—

First district,	right	bank,	130	miles ;	left	bank,	0	mile.
Second „	„	„	64	„	„	„	124	„
Third „	„	„	173	„	„	„	185	„
Fourth „	„	„	407	„	„	„	200	„
Totals	right	bank	774	„	left	bank	509	„

Or a grand total of 1,283 miles of levees on both sides of the river below Cairo.

The cubic contents of levees standing in 1882 have been given by Captain Townsend at about 32 millions cubic yards. This had increased by 1895 to about 99 millions, and at the present time is little short of 110 millions cubic yards.

Levee requirements.

The requirements of levees, or protective embankments along the river front, are, as concisely expressed by Captain Townsend, as follows:—Sufficient height above floods to prevent their being overtopped; sufficient mass to avoid surfaces of saturation being formed, on which the superincumbent material might slide; such width of base as will prevent the creep or pressure of water in the foundations from forcing out the material of the embankment on the land side; the protection of slopes from erosion by rains; and the protection of the water slope from erosion by waves during floods, or by river current where the embankment is close to a front of the natural bank of the river.

Materials of which levees are composed.

There are great variations in the description of soil of which the levees are constructed, very similar to those found in the Indus Valley.

It should first be stated that the whole of the Central Valley is of prehistoric origin, excepting the Delta and such portions of the Valley within the oscillation of the river where banks have been built up in recent times by the working over of the older deposit. The characteristics of the materials found on or near the surface, within the lateral oscillation of the river, are therefore similar throughout the Valley, whether found in recent or older deposits. They consist of clay, loam and sand, pure or mixed.

Clay.—The clay is of a blue, plastic variety, very stiff and strong. Even where of recent deposit its origin was from the original "Boulder-till" of the drift period, which has been brought down by the river and built up in the banks. It is commonly known as "Buck-shot," a name given to it because of its breaking up into round fragments of the size of large shot or bullets after it has weathered and dried out. It forms a good material for construction, but, when pure and unmixed with other material, does not stand very well at a slope of 3 to 1. When mixed with sand it is the best material available and makes an excellent levee.

Loam.—The loam consists of a fine light soil largely sandy in composition but, owing to the periodical heavy rain common throughout the valley, it has a stiffer consistency and is heavier than that usual on the Indus.

Sand.—The sand varies in size like that of the Indus, but is a preferable material for construction of levees on the Mississippi, because, when put into the bank there, it is generally more or less moist and consolidates better than does the dry sand of the Indus Valley.

Pure sand is much distrusted as a material for construction owing to its looseness and the difficulty in consolidating it sufficiently to render it impermeable. It is also liable to slip when wetted, even when the slopes are flattened out. There are similar objections to loam except that when grassed or sodded it stands well at grade.

There is usually, however, little choice in the selection of material for the levee. It is built, as a rule, of earth obtainable within a reasonable lead, generally from borrow pits on the water side immediately in front of the levee itself. A berm of thirty feet in width from the toe of the water slope is left and the pits are deepened as the excavation departs from the toe, till at a distance of about 100 feet the depth may be as much as from four to five feet.

Precautions in construction.

The precautions taken in practice now on the Mississippi are generally similar to those recognized of late years as necessary on the Indus. The ground is thoroughly cleared of all trees and vegetable matter, stumps and roots are dug out, or, when large and not otherwise manageable, are blown out with dynamite. The base of the embankment is then broken with a plough, and in bad ground where the material is changing quickly, or at crossings of depressions, a "Muck Ditch" or core trench is dug out of varying dimensions to give a better junction with the underlying material.

The earth is taken from the borrow pits by barrows or scrapers, preferably by the latter, as the tramping of the mules and traffic of the wheels assist in breaking up and consolidating the material. Of late years the wheel-scraper has become very popular, not only on river embankments, but on canal works in Canada, and generally on embankment works of all kinds throughout the whole of the American Continent.

The writer saw them at work at several places. At one loop embankment on the Mississippi, where the ground was very hard,

being pure buck-shot clay which had only lately been drained and was not only stiff but heavy and strong, the work was proceeding in very good style. Though the plough was continually employed to break up the ground in front of the scraper, a span of four mules was necessary to drag up their load which gave them as much as they could manage on the slope of the levee. The results were excellent as regards consolidation of material, though it was wetter than the writer would like to see put into levees or water embankments in India, where it is afterwards exposed to a continuous hot sun. Even in the Mississippi Valley levees made of buck-shot clay are found to crack and have to be carefully watched as the river rises on them.

Cross-section.

Practical experience has developed certain forms of general application, though these are sometimes changed to suit local conditions.

Water-slope.— A slope of three to one, well sodded, with Bermuda grass (a jointed running grass which spreads by putting out new roots at the joints), is found to resist the action of rain and of river currents as a rule. It is now generally adopted for the water-slope of new levees or loops.

Crown.—The width of crown varies from six to ten feet, but eight feet is general. It provides space for patrolling, and for storing material for the repair of damage during floods.

Land slope.—A land slope of three to one is now common, but for banks of greater height than twelve feet a banquet on the land side is generally recognized as advisable. The anquet, or berm, varies in width from twenty to forty feet, according to the height of the levee and the character of the foundation. The crown of the banquet is given a land slope of about one in ten for drainage purposes.

In the fourth District, where a large portion of the work has been, and is being done by local State Engineers, the form of section generally adopted is as follows:—Width of crown, 8 feet; river slope, 3 to 1; land slope for 6 feet from the top, $2\frac{1}{2}$—3 to 1; the next 6 feet slope, 4. to 1; and below this, 6 to 1. This section probably more nearly fulfils the requirement as regards strength than any other, if it could be built of full eventual requirement or section at once. But there are practically no lengths in existence where such is claimed to have been done. The objections to it are that the material taken for

topping during floods is situated far down the slope ; it does not lend itself readily to enlargement ; besides, in the original construction, it involves additional trouble owing to the changes of slope.

The writer gathered that the banquet form is generally considered to have many advantages. It provides space for materials and also for a roadway in time of floods when the back country, especially in depressions, is covered with seepage water ; it affords material for the topping of the levee when necessary during high water, and also gives a better form of cross-section for subsequent enlargement or raising.

The general conclusion is that the section with banquet is the best form for general adoption. Most of the new levees now being built under the direction of the Commission have this cross-section, with variation merely in the width of banquet and occasionally of slope to suit special requirements.

Grade of Levee Line.

The general grade adopted has varied in the different districts. The history of levee construction has been somewhat similar to that of the embankments on the Indus ; as the lengths of levees protecting basins have been extended the flood levels have been raised, and enlargement and raising of former levees have resulted as a necessity.

Provisional Grade.—Consequently, throughout the Lower Mississippi Valley the different districts are now working to what is called a "Provisional Grade," it being recognized by the Engineers that, with the limited funds allotted and the time available for construction between high waters, the best method of affording protection to the country is to work up by degrees to the eventual, or final, grade necessary for the whole length of river. Besides, they have to consider the difficulty of at present forming a correct estimate of what the eventual grade will be.

Heights adopted for provisional grade.—Previous to the flood of 1897, that of 1882 was recognized as the greatest flood of modern times of which records of height were definitely known. Grades adopted in the several districts were, therefore, fixed with reference to that flood. In 1896 the levees generally were completed to the provisional grade level.

The provisional grade was usually three feet above maximum known stage of the river in the length under consideration. In certain

short lengths it was somewhat less, while in others, as opposite basins, considerable lengths had a grade with as much as four to five feet free-board, or of height above flood level. The variations in heights adopted were due to the relative amounts of work necessary to bring the crown to any desired grade, the allotments available and time required for enlargement or completion. It was well recognized that as the upper basins, which formerly acted as safety valves or governors of high floods, were shut out, the increase in stage height would probably necessitate further raising of the embankments throughout nearly the whole of the length of the river, and particularly in the middle reaches. This has been confirmed by the experience of the 1897 flood, the highest on record throughout the whole length of river excepting the first 70 miles below Cairo.

It is, however, satisfactory to read in the report of 1897, after the experience of this great flood, that the Mississippi Commission record that "the important fact, that the flood waters of the Mississippi may be permanently controlled by a system of levees that can be constructed within a limit of expense, warranted by the advantage to be gained, seems to have been fairly demonstrated by the flood of 1897." They estimate that the works necessary to complete the levee system and to give satisfactory control of all future floods would cost about $18,000,000.

The 1897 flood was remarkable for its unprecedented high water in the Lower Mississippi, and also for its duration. It exceeded previous records at all points from 70 miles below Cairo to the sea by heights from $1\frac{1}{2}$ to $3\frac{1}{2}$ feet, as far down as Carrolton. The excess at Carrolton was 1·6 feet; thence it fell to four inches at Fort Jackson. In all 36 crevasses or breaches occurred in the levee lines north of the Red River Landing. Altogether $8\frac{3}{4}$ miles of embankments were carried away, and some 10,000 square miles of country inundated. A large portion of this is, however, not under protection of the levee system, being at the south or lower end of basins and subject to overflow from back water; it would have been inundated even if there had been no crevasses. South of the Red River Landing the levee stood intact, though exposed to a very serious test. It was only held by topping, or capping, added as the river rose to the level of the crown of the levee, and, in some cases, continued to rise to as

much as 2 to 2½ feet above it, incredible as this may seem. The methods adopted for holding the levees is a subject for separate description which will be dealt with further on.

To illustrate the influence which extension of levees has on high water discharge of the river, Captain Townsend examined the records of gauge height, cross-section, and discharges, at Lake Providence for a number of years from 1882 to 1893. After discussing the figures of measured discharges and of flow across the alluvial valley, he shows that out of an estimated flow across the valley of 2,000,000 cubic feet per second in 1882, only 1,057,000 was measured as the discharge of the river; and of 1,750,000 flowing across the valley in 1893, the discharge of the river had increased, according to measurements, to 1,498,000 cubic feet per second.

The increased discharge of floods held between levees has been accompanied by a rise of several feet at different points along the river.

Cross-section Lower Yazoo District.—Mr. Starling gives the following as the usual cross-section in the Lower Yazoo District, *viz.*, crown, eight to ten feet; slopes, three to one; with a banquet of twenty feet width and outside slopes of 4—5 to 1. The slope of crown varies from one in ten to one in twenty.

It may be mentioned here that banquets or berms are never built on the water slopes of levees on the Mississippi, it being agreed that the placing of the banquet on the land side has many advantages, while, at the same time, it is considered capable of providing practically the same strength to withstand water pressure as if placed on the water side.

Distribution of Grades.

The slope of the water surface varies considerably with the stage of the river in the length concerned, especially when short reaches are considered. And when the levee line makes a sharp turn and line of re-entry towards the river across its former direction, this ponds up the flood water along the face of the levee, often to nearly the same height as it stands at for quite a considerable distance upstream. Where changes in direction of the levee line occur this fact must be steadily borne in mind in fixing its grade.

The grade of most levees, if correctly fixed with reference to alignment and maximum high water along the face, will be a succes-

sion of alternating flat and steep inclines or slopes, and not a continuous slope. By "grade," as used here, is meant the crown line indicating the free board provided above the line of surface of maximum flood on the face of the levee concerned.

Muck Ditch.

There is a difference of opinion about the necessity for and utility of the muck ditch. In cases where the new line of levee crosses drift sand, as, for instance, at a new loop behind the old line which has been broken or breached, leaving waves of drift sand over the original ground, there is probably no doubt that a muck ditch or core trench is advisable to make a good junction with the original ground. So also is this the case at crossings of bayous or old channels, where the top surface is often not consolidated.

But generally where the base of the levee rests on ground more or less of the same character and tolerably even, there is nearly a consensus of opinion that the only advantage gained by construction of the ditch is a better break-joint against the creep of water when the levee is first wetted. Mr. Richardson, a State Engineer of long experience on the Mississippi, has expressed his opinion that the extra cost of the core trench can best be expended on additional earthwork for the enlargement of the cross-section. This remark, the writer thinks, may be applied more especially to levees of twelve feet in height and under. Above that height greater attention is necessary to the general dimensions adopted for the cross-section to suit the conditions, not only of greater water pressure, but also of the ground on which the base of the embankment will rest and the material of which the embankment will be built.

No doubt a shallow and broad muck ditch gives a good break-joint, and its construction further secures the thorough examination of that width at least of the base and the removal from it of vegetable matter and roots.

The result of experience is that ample provision must be made for settlement. Theoretically this should vary according to the height. Across bayous or depressions, where the height of the levee is in some cases as much as twenty feet or even more, and where the ground is generally of softer material, extra provision for settlement is advisable. The general rule is to allow one foot in ten for settlement. This extra height above grade is built by the contractor without extra

payment, the measurements on which he is paid being those of cross-sections with heights required by the grade levels.

Letting water against new Levees.

Endeavour is made to build new loops a year ahead of their being called upon to do their duty of protecting the country behind, in order that they may be consolidated and be better capable of resisting the water pressure against them. The practice of the Lousiana Engineers is, so says Mr. Starling, when it is seen that the loop will be called upon to do its duty, to cut the old levee in several places and to let the water against the new bank gradually, in order to avoid a rush of water against the new work. The chief advantage of this practice is that it gives time to repair leaks or other defects as they become evident with the slowly rising water. Settlement is gradual and the sudden strain due to a quick rise is avoided.

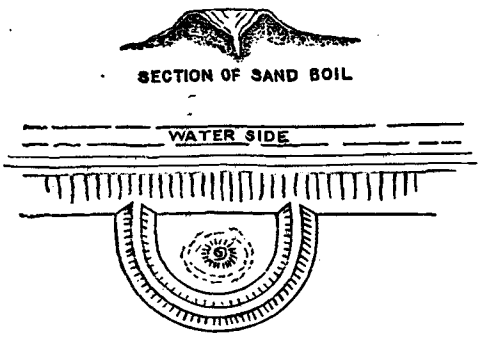
Care of Levees in the Flood Season.

Seepage water.—Though the embankment itself may be sound there is a certain amount of seepage through the bank, or leakage of water underneath the bank due to the looseness or want of consolidation of the materials composing both the bank and the ground. Especially in old levees, or in enlargement of such, is this more evident, in consequence probably of the original ground not having been thoroughly cleared of stumps and roots.

Again the leakage may be due to holes made by rats or other animals letting in the water to positions half-way or more through the bank itself. Thence the water may find its way to the land side by washing away particles and enlarging the pores, eventually causing a slip on the land slope if the high water lasts sufficiently long; or it may work through the subsoil and finally come up quietly to the surface in sand boils of varying size.

Sand boils.—These boils or exits of the seepage water sometimes develop sufficiently to undermine the land slope, which then slumps down and if neglected, they may develop quickly into a breach. Sand boils are therefore carefully watched. Those in which the sand is merely playing in the exit are not dangerous, but when discolored water passes or is carried outside the rim of the boil, there can be no doubt that the leakage is carrying off material and is gradually enlarging itself. A muddy seep or boil is therefore always suspicious.

If discharging muddy water it may be bottled by building around it a small embankment, or by making a small low loop embankment on the land side of the levee to enclose it, as shown in the margin. The space enclosed within the low embankment of the bottle or of the hoop serves to hold or pond up the water and thus relieves the pressure causing the discharge of the seepage or boil.



HOOPING A SAND BOIL.

Mr. Starling says, "There is no incident of high water mark that is more alarming to the novice than the sloughing or slipping of the land side of the levee, when water is standing high against it on the river side. This is an accident which frequently happens to green levees, especially if built with wheel-barrows and without tamping. While this would be a formidable evil if unchecked, it is one not difficult to remedy if men and materials are at hand." He recommends buttressing up the slipping earth with lines of stakes and brushwood and poles laid between them, and then after a dressing of brush has been laid on the sloughed material, fresh earth is thrown thereon till the section is restored to something like its former shape. He points out the danger of overloading, as this only makes the slough worse, and adds "it is sometimes advisable to put in a brush drain to lead off the water."

Sloughing of Levees.

This method of dealing with sloughs is common in Sind. Mr. Richardson, Chief Engineer, Lousiana State, as will be seen in his note on the lessons of the 1897 flood given further on, speaks in no undecided terms in favour of putting the earth on the water side in preference to the land side, in order to stop sloughing. Mr. Hardee, Assistant Engineer, Lower Tensas District, is of the same opinion.

He, Mr. Hardee, says, "The only effectual method of stopping sloughing is to stop its cause, that is, the percolation of water through the embankment. The treatment consists in dumping earth in the

water over the river slope ; the particles become swollen and the leak is stopped." In illustration of the success following this principle of applying the remedy to the water side, he describes how leaks are closed in seams of coal barges. The seams are not caulked from the inside of the barge, which would involve trouble in removing the coal, but the bargee lowers a cupful of saw dust at the end of a stick into the water, and then shaking it close to the leak the saw-dust is carried in with the water and becoming swollen closes the leak. Similarly with sloughing levees, the good effect of earth on the water slope is soon seen by the reduction in seepage, and in inclination of the land slope to slip. The blanket on the water slope is thickened and enlarged, seepage ceases, and the land slope dries out. He advises their being dealt with in the earlier stage, and remarks, that to the experienced eye the accumulation of moisture on the land slope is sufficient indication of a threatened slough, which can often be easily stopped by a thin blanket of earth on the water side and a little drainage on the land side.

Treatment of subsidence in levees.

When sloughs are due to the bad material of which the levee was made, they are often accompanied by settlement of the levee itself, sometimes uniform but often greater on the land side slopes. The rear half of the bank then separates itself from the front, leaving a longitudinal crack, and reducing the useful part of the bank to withstand water pressure to less than half its original section.

To render the levee safe and prevent it breaching, it is then necessary to thicken up the front side by blanketting the water slope heavily with new earth, either loose or in bags. The blanketting is sometimes assisted by a revetment of short piles driven at a slope to form a crib to hold up the new material. This crib proves the more useful if the settlement continues and a capping to the embankment becomes necessary to keep the general level above that of the water. The capping may be of loose earth or, if exposed to waves, of sand bags, more correctly earth bags, laid in tiers breaking joint with each other. It is stated that subsidence frequently continues until quite a considerable banquet forms on the land side. The longitudinal crack should not be filled. as this would merely tend to further open it out, and all capping should rest on the water side of the crack.

Capping.

The reports of 1897 give accounts of the remarkable success possible in fighting a river by capping the embankment with earth supported by crib work and with bags. It is related that many miles of levees were thus raised from $1\frac{1}{2}$ to 2 feet in height, and were successfully held with the river level at a height of from 6 inches to as much as $2\frac{1}{2}$ feet above the original grade of the levees. The bags and timber were delivered at convenient points in barges according to the requirements; and it is said experience shows that when the levee is below the standard of safe grade it is advisable to have store-houses along the levees in which to keep a stock of materials ready for an emergency.

The accounts of the quantity of material used on this merely temporary work, its cost and difficulties, are in the writer's opinion, merely an additional proof of the advisability of making greater effort in the working season to bring the levee to standard section. One dollar spent in permanently strengthening the levee at weak places is worth a good many more spent in the flood season.

In capping with sacks, two sacks filled with earth are laid abreast near the river-side edge of the crown, forming a base two sacks wide, and additional rows of sacks are placed on the bottom tiers until the desired grade is reached, all joints being broken to minimize leakage. The sack capping is then backed by earth well tamped by hand mauls to the extent admissible by the width of the crown.

Protection of slopes.

The levees of the Mississippi are generally much more exposed to wave wash than those of the Indus, and great difficulty is sometimes experienced in defending them against the erosion of waves. Especially is this the case in the lower reaches of the river, where there is an absence of forest growth, and where the levees are often built immediately on the natural bank of the river. Even where levees run through forests in the upper reaches, they are much exposed to the wash of waves when situated near the river front. The trees, generally cypress, of the older forests are of large growth, as much as 15 to 24 inches in diameter, with but few branches in the lower 10 to 20 feet of their height from ground-level, and there is little natural protection to levees on the river front except that given by willows. In places

this is excellent, especially where there is a new growth on an accretion, but the heavy demand on them for the construction of mattresses thins out a good deal of the older willows bordering on the face of the river.

On the upper reaches the levees are generally set well back from the river, and the Bermuda grass, specially cultivated on the slopes, usually proves sufficient protection. In years of exceptionally high floods it is however necessary to resort to temporary expedients to save the slope of the levee at exposed places from erosion.

Temporary protection.—The temporary remedies adopted include laying down refuse of sugarcane, cotton stalks, earth bags, planks, washboarding, and wooden revetment.

Permanent revetment.—In very exposed situations permanent plank revetment is resorted to. The extent of this, particularly South of New Orleans, was a complete surprise to the writer. The levee face is there close to the bank of the river, and is protected mile after mile by what is practically a permanent plank revetment.

It consists, in the lengths examined by the writer, of two thicknesses of 3-inch planking standing at a batter of about one in four spiked to horizontal stringers, fastened at each end to posts which have a hold on the ground at the toe of the slope, and are given additional support by struts butting on the face of the levee. The life of the structure is limited, it is said, to from 12 to 15 years; and the writer gathered in the course of conversation that the question of replacing the older parts of the work, possibly by brick or some other material better than wood, may soon have to be considered.

Temporary wooden revetment.—A lighter form of the above is built as a protection against wave wash and erosion on levees made of sandy or light soil in exposed places. The posts are 3 × 3 inch scantlings and they are driven at distances apart of from six to eight feet into the slope of the levee at the water edge, with batter towards the crown. They are anchored back by 6 × 2 inch braces, fastened to anchor stakes driven into the crown of the levee, and are framed or joined by horizontal pieces at top and bottom. Inch boards are then placed horizontally and fastened to the post by nails to a height of about three feet above water-surface to prevent their being overtopped by waves.

Washboarding.—This is a still lighter form of wooden revetment useful only for fighting high water. It is resorted to for protection of new topping, and consists merely of inch boards nailed to vertical stakes driven in the bank near the water's edge.

None of these forms of wooden revetment are suitable to the Indus levees, as the cost of timber for their construction would there be considered prohibitive ; but capping and protection of the slope with earth sacks or bags might apparently be adopted with advantage at severely tried points difficult to hold in extreme cases. Mr. Starling says that "with plenty of sacks and a well-organized and well-equipped force, a competent high water foreman will hold a sound levee of standard dimensions against anything short of a hurricane." The bags should be laid with great care in regular courses, and against a violent wind may be laid as headers with their ends butting on the slope, or as headers and stretchers, making the thickness that of the length of a bag.

Crevasses.

The general method adopted on the Mississippi for closing crevasses, or breaches, is in principle the same as that followed on the Indus, with additional refinements due to experience and facilities in obtaining suitable materials.

Large crevasses have occasionally been successfully closed, but it seems to be generally admitted now that, unless the breach is closed soon after it occurs, or the shallowness of the water and nature of the ground promise decided success, attention had better be directed to prevention of enlargement of the crevasse. The ends of the levee are therefore protected with earth bags, and short spur dykes are built out at right angles to the levee near the broken ends to protect them from the rushing eddying discharge through the crevasse.

The "Creole Plan" of closing crevasses.

Mr. Starling describes what he considers the only successful method of closing a breach, called the Creole Plan, as follows :—"This plan may be likened to the operation of raising a moveable needle dam.

"First, a number of bents are set up, analogous to the trestles of a Poiree dam, then stringers are placed to connect the bents, and lastly hand piles are driven in front of the stringers, supported by the latter in place of the needles. The work is completed by filling in with sacks and earth." He says the first thing to be done is to get

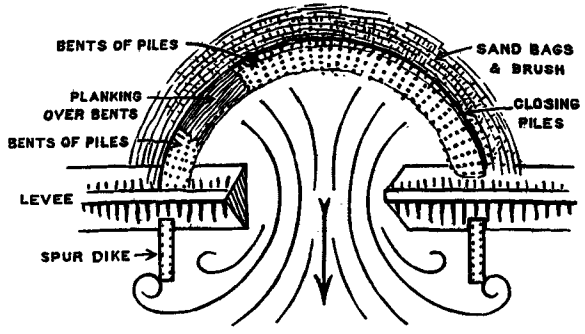
Crevasse on Stokes' Plantation (380L), April 12, 1897.

Rear View of Break closed by Sandbags, on Stokes' Plantation (380L), April 12, 1897.

materials together, then sacks are filled, and while this is in progress the bents are driven.

For small levees, bents composed of from three to five hand-driven piles may be sufficient. The work should proceed from both ends of the break, driving bent after bent by standing on the ends of a run plank projecting beyond the bent previously driven. This brings the bents about four feet apart. The piles are braced together as fast as driven, and stringers placed in position as the bents are set up. The pile work thus constructed is floored over with planks on which are stacked piles or planks in quantity enough to close the work and also a sufficiency of sacks filled with earth.

The closing piles are driven merely near enough together to keep the sacks from passing through. "They are driven as nearly as possible simultaneously along the line, as many men, with heavy mauls, being employed as can work to advantage. Thus the final operation of closing the line may occupy less than an hour. The sacks are then thrown in front of the continuous line of piles as rapidly as possible."



The alignment adopted for the pile work and the location of spur dikes for protection of the broken end of the levee are shown in the marginal sketch.

Mr. Starling mentions that in several small breaks successfully closed in this way the use of brush, in addition to sacks, was found of great assistance. Brush was thrown into the water in front of the pile dike and pressed to the bottom with forks; then this process was repeated until the brush reached the surface of the water, and on it sacks were then thrown until the breach was closed. The brush serves to economize earth and to give continuity and bond to the structure.

LESSONS OF THE 1897 FLOOD.

COMPILED in the Chief Engineer's Report for 1897 will be found reports of Mr. Starling, late Chief Engineer, Mississippi. State Levees, and of Mr. Richardson, Chief Engineer, Louisiana, on the lessons of the 1897 flood, written in response to a request made by the Mississippi River Commission. Both have had a long experience of the Mississippi, and are recognized as capable River Engineers. The writer had the privilege of spending several days with each and many opportunities of discussing special points with them. The confidence thus acquired in their opinions, the information and instruction conveyed in their deductions more than justify his quoting largely from their reports.

Mr. Starling says: "The standard cross section of new levees has proved itself sufficient as far as the embankment itself is concerned. Weakness has, however, sometimes been revealed in the natural soil underneath the levee in lengths where there was no banquet. When there was a banquet, no trouble was experienced either with boils or sloughs. In places formerly distinguished by very large and ugly boils the difficulty has been entirely suppressed by the construction of banquets."

In his opinion no large levee should be built without them, unless it is evident that both levee and underground will be composed of the strongest soil; and when the material is very light the banquet should be placed six feet below the grade of the crown.

Small levees may have a crown of eight feet, but in larger ones ten to twelve feet is better. Side slopes of three to one, except in much exposed situations or with large levees in light soil are generally sufficient. He says: "Levees built up to these dimensions with banquets, when constructed with proper care, even though the foundations be of weak soil, may be relied on to hold still water up to their very tops; for storms a margin of safety of two to three feet is required." This statement is founded on long experience.

He mentions that of the breaches which occurred in the Yazoo front not one was in a new levee; further that old levees, though

generally bad, are not useless, they can be utilised by adding to their front slope and to the back slope by the formation of a banquet.

Summary of Mr. Starling's deductions.—The following are excerpts from his summary of the lessons of the flood :—

"The standard cross section of crown eight feet or more, side slopes one on three, and banquets for heights over eight feet, is sufficient for ordinary soil. For exceptionally weak soils special dimensions must be adopted.

"The foundations must be carefully prepared.

"The levee should be so built as to keep tolerably dry if possible. It should therefore be put up in layers, and preferably should be rolled.

"Old levees cannot be depended upon, not because of their age, but because they have not been properly constructed and are probably unsound. In enlarging such levees a greater volume of earth should be added than with new and sound levees. Banquets are especially indicated.

"Steep back slopes are to be avoided, and especially such as present a hip or hump.

"A more careful discrimination is necessary between soils than has heretofore been customary. . . . In building new levees in very light soils banquets should be added even with levees of ten feet in height or less.

"New levees are liable to shrink or settle or both, when water first comes against them ; also alarming boils or sloughs may occur. It would be well then to let the water against them at comparatively low stages, that opportunity may be given for repairs.

"Buck-shot levees cannot be depended on to stand at grade. These and levees across beds of old water-courses should always be built to high grade.

"Topping is unsafe when the water stands high against it, especially in situations much exposed to waves.

"While it cannot be said that closing of large crevasses at extreme high water is practicable in any limited time, still, in favourable circumstances, the situation may be mitigated and relief given in many cases before it would have come from the natural recession of the water."

Mr. Richardson's Report.—Mr. Richardson writes to the following effect: There are altogether 1,072 miles of levees protecting the

alluvial lands of Louisiana, including fence and back levees to shut out back waters. The 1897 flood was held in complete control from south of the Atchafalaya for a distance of 332 miles along the Mississippi. "Hundreds of miles of levees were raised with earth, or planks or sacks." The efficiency of the control was partly due to the immense assistance in labour and materials given by the U. S. Officers, Local Levee Boards, and private parties during the progress of the flood for the protection and preservation of the levees.

"Notwithstanding the fact that the flood reached much higher stages in the river than any previously recorded, by nearly 3½ feet along some parts of the levee lines in Louisiana, and by over two feet against the major part of them, it is noted that every drop of it, (except the insignificant volume escaping through the crevasses of Bayou de Glaizes,) was successfully carried between levees from the head of the Atchafalaya Basin to the end of the Levee Systems near the Gulf."

Mr. Richardson advocates a grade line three feet above the high water line of 1897, as a tentative standard to be worked to for the present; though he states, as a matter of course, it would be better economy to build at once to a still higher grade if the available means and the time available for the work would warrant such an undertaking.

"As to the form of cross section best adapted to fulfil the purposes for which levees are designed it can hardly be said that anything was demonstrated by this flood. Nothing has been developed by the late flood to impair confidence in the sufficiency of grade proposed by your (the Commission) Committee on Levees, given in the report of 1896.

"That form of embankment that will best retain its shape when completely saturated with water still seems the best and safest. As the lower portions of a levee are generally less dry than the upper parts, there may be reason in giving the section flatter slopes toward the base than near its top, but generally speaking the form of section having a bench or 'banquet' on the land side, seems to serve all the purposes of a flattened slope, and indeed approaches the usual form naturally taken when its sloughs down and comes to rest in a position of stable equilibrium.

"Levees built of almost any sort of earth, with side slopes of one on three, have generally stood without any sloughing of consequence, wherever the seepage water was well drained away from the base; but

when drainage is deficient, and also when the soil appears excessively loose and friable, the addition of a banquet, or construction with a flatter land slope, is found to give stability.

"A few facts connected with levee construction and maintenance, though by no means new, may be mentioned as having been emphasized by the experience of this flood, such as the danger, more than ever apparent, that earth added to levees in enlarging them on the land side may slough and slide down during high water or whenever it is first thoroughly saturated, even if that condition is delayed for years, and the consequent importance of placing all levee enlargements except that in the form of banquets on the river side wherever practicable; the importance and value of good drainage as a means to prevent sloughing, and to dislodge or at least discourage the depredations of burrowing animals; and the fact that to stop leakage or excessive seepage—in fact for almost any other purpose with which earth is added to levees—one spadeful of earth put on the water side of the levee is worth dozens placed on the land side."

He finally recommends that gaps in a line be closed, and the enlargement of levees throughout the valley be carried on as rapidly as means therefor can be made available.

Mississippi Commission Committee's Report on final grade.

The Committee referred to by Mr. Richardson gave an estimate of the expenditure required to bring the grade of the whole levee system to final height sufficient to confine all future floods. They pointed out: "The question as to what heights future floods may be expected to attain, with the flood waters confined by sufficient levees, is one upon which there is some difference of opinion, and the question does not admit of any exact solution other than by the actual experience of the passage of a flood of sufficient magnitude to develop the flood slopes within leveed banks."

After careful consideration the Committee estimated the probable increase of flood heights at different points from Fort Jackson to Cairo and, allowing a grade for the levee line of two feet above these assumed final flood heights, they estimated that the cost of raising and enlarging the levees to these heights would be $18,300,000.

Their estimate of increase in flood heights above recorded maximums, previous to 1896, varied from one foot at Fort Jackson to six feet at Vicksburg, and from six feet at White River to two feet at Cairo.

LEVEE CONSTRUCTION IN 1898.

One of the most valuable lately written opinions on Levee construction found by the writer is that of Captain Patrick, U. S. Corps, the officer in charge of the first and second districts in 1898, expressed in a letter to the President of the Mississippi River Commission in August 1898, in connection with an estimate of the total additional yardage required for completion of the levee lines to the standard grade.

He speaks of the method of construction by teams and scrapers, and, in exceptional cases, by wheelbarrows, as the most economical yet devised to give good results, but suggests that improvements in methods, "resulting in better work, cheaper work and an earlier completion of the entire levee system," could be made if there were an assurance that it would be pushed continuously to completion, and that a certain definite sum would be available each year until finished.

"*Location.*—While nothing is said in your letter about location of levee lines, this is a subject which I (Captain Patrick) think demands consideration. In the practice at present followed, I am convinced that sound engineering principles have in many cases been made to yield to other motives in the choosing of courses to be followed by levee lines. This has been due to several reasons, partly to the idea originally followed of improving the navigation of the river by controlling the high waters, partly to the fact that this location was done in conjunction with levee boards which were more or less influenced by considerations affecting their immediate constituents, partly to the fact that the small amounts of money available made it necessary to simply enlarge existing levees rather than to strike out on newer and better lines. The levees have closely followed the river in its meanderings, and at places have been built near to caving banks for the sake of protecting for a time the land in their immediate vicinity. While much of this work cannot be undone, there is still room for betterment if the entire problem is to be considered as a whole and its systematic solution undertaken. I believe thoroughly in avoiding salient angles and in shortening and straightening the line wherever it can be done at approximately the same expense as would

be incurred in enlarging the existing longer line. In doing this, smaller private interests must give way to larger public ones.

"*Construction: New Levees.*—It must be understood that all rules laid down for the construction of levees are of a general nature, elastic, and to be modified according to the local conditions. At present the ground to be occupied by the levee is to be cleared, all stumps, roots, or other perishable matter grubbed and carried outside of the base of the levee. In some cases, if properly done, this may be a sufficient preparation; where much vegetable growth occupies the site, I think it well to go further and take off a foot or 18 ins. of the surface: if there is to be a banquette, the material so removed, if of suitable character, may be placed in this banquette; if there be no banquette, this method may be followed over that part of the base in front, and the material put on the land side of the centre line of the levee. Similarly, the earth obtained from the first ploughing of the borrow pits should be put in the banquette or on the land side of the centre line of the levee.

"*Layers.*—If the levee be carried up in layers as is now the custom, the above suggested method would enable the layers to be given a slope up from the river side, which would be an advantage. My specifications limit the thickness of the layers to 2 ft. This is as thin as they can be made by present methods of work with a due regard to economy. It is certain that a much more compact levee could be built if the thickness of the layers could be still further decreased. The passage of teams and scrapers over 2 ft. layers does not sufficiently compact the earth.

"*Construction: Enlargement of Old Levees.*—If the old levee besides being too low, has shown signs of weakness, seeping badly or sloughing, it must be carefully explored; any immediate cause of the weakness must be removed. A general remedy for such cases is the cutting of a muck ditch of liberal dimensions on the river side involving a part of the slope of the levee, and filling it with select material well tamped. I now have the contractors waste the sod destroyed on the slope to be enlarged, and re-break the exposed surface before putting on the new material. If covered with earth, this broken sod decays and is an element of weakness.

"*Topping.*—I believe it well to place a topping of earth on the levee above the selected grade line, bringing it to rather a sharp crest.

This is useful where the maximum high water line is not well established, and when the grade adopted is a tentative one ; it supplies at much less expense earth which may be badly needed during high water. It also prevents, or allows for the damage to the levee from traffic over it, a thing which unfortunately cannot in all cases be prevented.

"*Slopes and Crowns.*—In general, I have found levees built to the adopted standard cross section with crowns 8 ft. wide and slopes 1 on 3 amply strong enough to withstand the pressure brought against them by the water. In cases where the levee crosses bayous or washouts, I have flattened the land slope to about 1 on 5.

"*Banquettes.*—The heterogeneous materials, of which levees are built, and the varying periods for which they are subject to water pressure, make difficult any reliable determination of the line of saturation. I am of the opinion that all levees of a greater height than twelve (12) ft. should be reinforced by a banquette whose dimensions must be suited to the special case under construction. It is recommended as a general rule, that these banquettes should be built with the following cross sections ; for a levee 12 ft. high, the banquette to intersect the levee 8 ft. below the crown, to be 20 ft. wide, banquette crown to have a slope 1 on 10, rear slope 1 on 4 ; a levee 20 ft. high, banquette 40 ft. wide, top slope 1 on 10, rear slope 1 on 5 ; proportionate dimensions of cross sections for other heights.

"*Drainage.*—There is little or no doubt that the stability of levees would be increased by some properly devised plan of drainage; probably the best yet suggested is the employment of porous tile pipes placed near the land toe of the levee, with openings at intervals to a ditch in rear. When experience has shown that a levee is weak, inclined to slough or seep badly, such a method of draining the levee may be of great advantage. In a properly contructed levee built of good material, I do not believe the advantage gained by tile drainage is worth what it costs. This opinion is reached after a study of the levees along my own districts, the upper part of the river, where the duration of floods is at present less than on the lower reaches.

"*Muck Ditches.*—These ditches are important component parts of levee construction in many cases. My practice is to examine the special locality before deciding upon the need of a muck ditch, or, if

it be necessary, upon its dimensions. Where there is a considerable grubbing in the base of the levee, a fair idea of the character of the underlined strata can probably be obtained from an examination of the stump holes; elsewhere holes are dug or short narrow trenches excavated to considerable depth. Where the levee is to be founded on a fairly impermeable stratum of soil reasonably free from perishable matter, the muck ditch may be omitted. Where the foundation is of light porous material, or where permeable strata occur a short distance below the surface, a muck ditch should be cut and filled with good material, well packed. If possible, the bottom of the ditch should be in a less permeable stratum. This ditch must generally be wide enough at the bottom to permit the passage of a team and scraper; the side slopes may be as steep as the material will stand; the top width will depend on the depth and side slopes."

Mr. Starling on above in 1898.

In replying to the call made by the President of the Commission for an estimate of final cost of completion of the levee system, Mr. Starling also touched on some of the points dealt with by Captain Patrick.

He expresses the opinion that large muck ditches "are an injudicious expenditure of money;" he thinks they are "principally of value as exploration ditches, to show whether any stumps, brush heaps, &c., have been covered by recent deposit." . . . . "As a constituent part of a levee, however, it is believed that the cost of a large muck ditch is out of proportion to its usefulness."

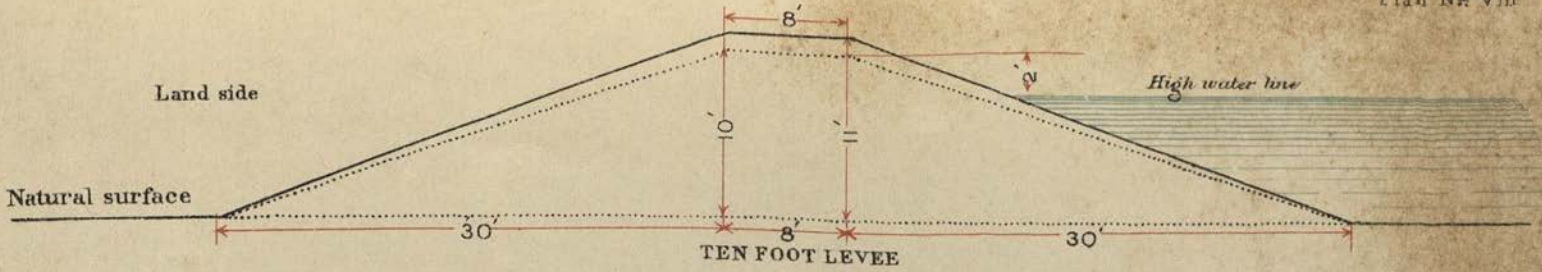
Regarding the drainage of the levee, he again repeats his former statements that "usually the cavities which exist and which are inhabited by crayfish, are due to decaying stumps, and the channels which sometimes pass through the levees almost from side to side, to decaying lateral roots of trees." He recognizes the desirability of keeping the levee and adjacent land dry. "The levee is less liable to slough, it is more accessible to high water forces for purposes of repair or enlargement, the material is thereby rendered available for such work." Good drainage he regards as a requisite for successful and economical operation and maintenance. "If drainage is given by open ditches, great care should be taken that they are not too deep or too close to the levee, especially in light soils, as they have frequently been a serious menace to the safety of the embankment from the breaking out in them of sand boils."

Approved cross-section for Levees.

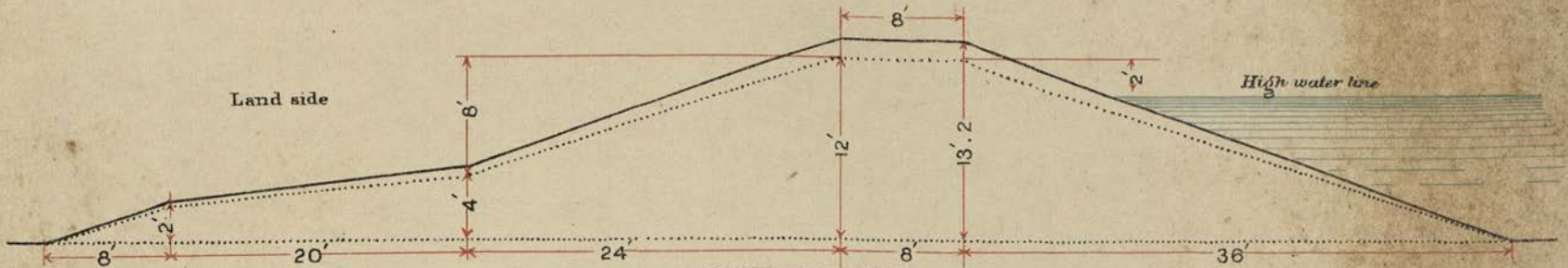
The opinions expressed by Captain Patrick in his letter of August 1898, quoted above, so generally agree with the writer's impression of the generally approved cross-section to be followed in the future, that he obtained a plotted typical section from Captain Patrick, the Secretary of the Commission, as an accompaniment to this note. (See plate opposite.)

Specification for construction of Levees.

A copy of the specification for the construction of new and enlargement of old Levees in force in the 1st and 2nd Districts in 1899 is given as Appendix B.



TEN FOOT LEVEE



TWELVE FOOT LEVEE

Typical levee sections as laid out for construction and actually built shown by full lines.

Assumed settlement and cross sections paid for shown by dotted lines.

As a general rule, banquettes are built along all levees 12 feet or more in height, intersecting the levee 8 feet below the crown. Width of banquette varies with height of levee, reaching a width of 40 feet for a levee 20 feet high. Rear slope of banquette for very high levees is often made one on five (1/5) instead of one on four (1/4).

Office of Mississippi River Commission,
Captain MASON M. PATRICK,
Corps of Engineers, U. S. A., Secretary.

C. W. CLARK,
Asst. Engineer.

EFFECTS OF LEVEES ON THE RIVER CHANNEL.

Opinions have varied as to the effect on the river channel of the construction of levees along its banks. By perusal of the earlier reports of the Mississippi Commission, it will be seen that, though it was not claimed that the deepening of the channel for navigation could be effected by levees alone, it was believed that their construction would hasten the channel improvement, by increasing scour and depth of river bed which they would produce during the high river stages. They were regarded as a desirable, though not necessary, adjunct in the general system of improvement of the river. As far back as 1884, it was recognized that the grade of levees should be, at least, the normal height of the bank of the river, or the height to which the bank would be built by floods recurring with sufficient frequency to exert an appreciable influence in building up the bank or enlarging the waterway.

Recorded opinions of the Mississippi Commission.

In 1885 the Commission recorded their opinion that "Levees designed to limit the high water width of the river, by concentration of the flood discharge of the channel, secure its deepening and enlargement by scour."

Then in 1892, a modification of the same view is expressed in a report of the Commission, of which the following is an extract:—"In reference to the general plan of which these projects (of improvement) form a part, it may be said that it contemplates, so far as concerns the main channel, the improvement of its navigation by the concentration of the discharge of the river, at all stages, within a defined channel by means of levees, bank revetments, and contraction works . . . . . the levees to control the high water discharge and secure the energy of the flood volume in scouring and enlarging the channel."

Later, in 1896, is found in a report of the Special Committee of the Commission, "To formulate a general plan upon which shall be based the future recommendations of the Commission with regard to the improvement of the river," a clear expression of the opinion of the majority of the Commission on this question. It is stated:—"There was always some difference of opinion as to the relative importance to be attached to levees as a factor in channel improvement,

some of the members being disposed to assign them a quite subordinate place, while others considered them a *sine qua non.* With further study and added experience this latter view gained ground, and has practically shaped the action of the Commission in this particular. As regards the necessity of an efficient levee system for the prevention of destructive floods, there has never been any difference of opinion."

The following is a synopsis of what is said to be a general statement fairly summarizing the views of the majority of the Commission on this subject in 1896.

But one cause is operative in determining the slope and shape of a river like the Mississippi, *viz.,* the volume of water discharge. This varies enormously with stage. But " no one can doubt that the flood discharge is the ruling element. The bed of the stream as found from year to year represents the work of the high river, and the difficulties of navigation are due to the inability of the depleted volume of the low river to work out a good and stable channel through the great masses of sand and other materials left behind by the flood. Neither correction nor permanent location of channel can be secured until the paths of the high and low rivers coincide, and the work of the former is utilized in scouring out and sweeping clear the channel which the latter is to follow . . . . When this is done, the depth desired can be secured by a simple limitation of the area over which the action shall extend. The attainment of this end can only be accomplished by controlling the high river, and this is the key note of the Commission's plan of improvement."

It seems it was contended in the discussion of this subject that the control of the waters carried by the river might safely cease when the top of the natural bank is reached; in other words, that the overflow as a factor influencing the *regimé* of the river might be neglected. The Commission therefore state, with reference to this point, that it is not contended that the extra amount of flood volume is necessary to establish the low water channel of the river, the bank full volume being ample for that purpose. " But the extra volume represents a vast amount of work which must be expended somewhere, and which may fairly be considered as beyond the control of the natural banks. Its effects therefore are erratic and irregular, leaving the main channel at some places

entering it again at others, forming cut-offs and generally upsetting the regimen of the river."

It is remarked : " The evidences of deterioration of the channel in places where overflow has been habitual are too obvious to need extended comment The contrast between the river above and below Vicksburg, although there is no material change in either the discharge or the physical conditions, is a very striking one from this point of view. The re-establishment of levees, it was thought, would in some measure remedy this state of things and, although time enough has not yet elapsed for a final conclusion, there is already a good deal of evidence to support this view."

It may be mentioned that in the discussion regarding relative importance of levees and bank protection as a means of improving the river channel, Colonel Stickney, Corps of Engineers, dissented from the general opinion as expressed above. In a separate minority report he recommends that a foremost place be given to bank protection in the general plan of improvement, though advising the completion of the levee system to a fair condition, and afterwards that it be strengthened as found necessary.

General Comstock on the question whether building Levees along a river causes its bed to rise.

In 1890, General Comstock, President of the Mississippi River Commission, wrote what was for that time an exhaustive memorandum on this subject. He, like many others, remarked on the often repeated statement that leveed rivers raised their beds higher and higher as the levees are raised and hence that levees will give no permanent relief against overflow.

He reviewed the conditions of the River Po and its levees and the evidence obtainable on the question of alteration of its bed level. As to the rise in the flood level as the waters are more and more thoroughly confined, he says, " It may be said that this was a necessary result of confinement, that the same thing occurs on the Mississippi, and that it will cease when the levees have been built high enough to contain the greatest floods. On the Po, thus far, during the last seventy-five years the effect of the confinement of waters in raising the flood level has far exceeded any tendency that confinement may have had to reduce flood heights by scouring the bed."

Then as regards the Rhine, which has long been leveed, he says : " If levees raise the bed of a river, here they should have produced

their full effect as they are rarely broken." However, it appears that on the Rhine the low water surface has, if anything, fallen in the last hundred years; the medium stage does not seem to have changed much, but the maximum stage shows a decided depression.

He next considers the Hwang-Ho or Yellow River of China, and quotes a letter from General J. H. Wilson, "a very competent authority," who distinctly states his opinion that an exhaustive survey would prove beyond doubt that silting of the bed has not taken place.

General Comstock deals with the Mississippi River, and, though at that time he had not very much reliable data at his disposal, he treated of his subject in sufficient detail to inspire a certain amount of confidence in his conclusions. His final conclusions are in effect as given below.

From the examination of the Po and Rhine it may be concluded that if their beds rise in the leveed portions (which is not certain from the data) it is at so slow a rate as not to be an important factor in the maintenance of a levee system.

The opinion so often held that levees cause a river bed to rise is probably due to the fact that the bed of a river does sometimes rise although leveed, and hence it is concluded that the levees cause the rise.

"Any sedimentary stream, having a definite succession of stages and discharges and flowing in its own alluvion, finally takes such a slope as will give a velocity sufficient to enable it to carry its sediment, whether derived from above or from its own banks and bed, farther down stream, without, on the whole, scouring or filling its bed. An average velocity less than this will give rise to deposits in its bed, or if it is crooked it will become straight, thus in either case increasing its slope and velocity towards their normal values. An average velocity greater than this will scour its bed, or if it is crooked it will become straight, thus in either case increasing its slope and velocity towards their normal values. An average velocity greater than this will scour its bed, or cause caving in its concave bends, thus increasing its length and diminishing its slope and velocity to such values as its bed can bear without, on the whole, scouring or filling. When, therefore, the slope of a sedimentary stream suddenly diminishes from that which it needs for a stable regimen, its velocity also diminishes; it drops part of its alluvion and its bed rises. Thus, when the Mississippi enters the Gulf, its slope

suddenly diminishes, its velocity diminishes, and it builds up bars out in deep water. So the Adige, where it reaches the low plains of the Po, needs for permanence a steeper slope than the country has, and raises its bed above it. In all these cases the bed would rise without levees."

He mentions another cause for the rise of bed, which however acts at a very slow rate. The Mississippi pushes its mouths out into the Gulf, and this increase in length requires a corresponding increase in fall of surface to cause the waters to flow out. The increase in length taken by General Comstock, at four miles in a century, would, with existing slopes, raise the high water surface at New Orleans about 7/10 of a foot.

Captain Townsend, Corps of Engineers' opinion on this question.

In the discussion on Mr. Starling's paper on "The Discharge of the Mississippi River" is recorded Captain Townsend's conclusions regarding the effect of levees on the river channel. He discusses the available data, compares discharges, cross-sections, gauge heights, &c., at Arkansas City, Helena, Lake Providence, Vicksburg, &c., and arrives at the following conclusions :—

Since leveeing the river banks the measured discharges have increased relatively to the estimated flow across the valley; the discharge section at Arkansas City has increased in area. Similarly an increase in channel section appears in the Lake Providence reach, there being a large addition in recent years to the width of river at bank full stage. He states that "Professor Whiting, by comparing recent surveys with the records of the Coast and Geodetic Survey, shows that there has been a perceptible enlargement of the river in recent years at New Orleans." He finally concludes his remarks on this point thus :—"Such evidence is not conclusive of a general law applying to the whole river. What may be termed accidental (unknown) conditions may have especially influenced these few localities." He next analyses gauge readings and discharges, not omitting to consider the effect of a cut-off which had occurred, and showed "that the same forces acting in the river at a low stage can now cause a greater lowering of the gauge at Lake Providence than formerly, while at the mouth of the White River the influence is not as great." In general words his conclusions are that the river channels were improved during the period under consideration.

Mr. Harrod's observations.

Mr. Harrod, member of the Commission and an Engineer of long experience of the Mississippi River, in the discussion referred to above, also remarked upon this question of effect of levees on river channels. His clear opinion though only expressed in general terms, is well worth recording here.

In the length of river from Cairo to New Orleans, there are about 175 crossings from bank to bank, and at each of these there are bars. "These bars with six to eight feet of water over them recur with sufficient frequency to make the low water surface conform to the general shape of the bed. In plotting the high and low water surfaces, it is clearly observable that the former present a more regular curve, and that the irregularities of the latter consist of depressions at and about the mouths of the tributaries with elevations at intermediate points.

"If the beds of streams are self-regulated, as is now generally accepted by Engineers, then the variations of discharge between parts of the river where it is augmented by the volume of the tributaries and the return of the overflow, and those parts where it is depleted by escaping into the basins, may be reasonably accepted as a cause of the depression of bed where the discharge has been habitually increased, and of the elevation of bed where loss by flow has been unchecked for a long period of time."

The sketch given on opposite page, which is a copy of one made by Mr. Harrod for the writer, illustrates the above remarks.

Mr. Harrod says :—"If the discharge is confined to the bed, and not allowed to escape over the banks, and is thus made uniform throughout the length of the river, with the exception of the additions from the drainage of tributaries, the bed should become quite uniform in depth and cross-section with an increase below each tributary proportioned to its discharge. Confinement of floods is being effected by levees, and though not of final height, yet since 1891 floods have been held at a considerably greater height than formerly."

"At present there is no conclusive evidence on the effect of this restraint, but the indications are that the deposits between tributaries are being removed by the greater uniformity of flood discharge caused by the prevention of overflow. Where levees have been improved and the flood discharge increased, its height is not proportionately

Map No. IX.

PLAN OF RIVER MISSISSIPPI
Q = 0·5 M.
Ohio River Q = 1
Q = 1·5 M. R = 50
Q = 1 M. R = 34
St Francis Q = 0·1
Q = 1·6 MILLION SFT PER SEC R = 48
White Q = 0·15
Arkansas
Q = 1·75 M. R = 50
Q = 1 M. R = 36
Yazoo Q = 0·1 M.
Q = 1·85 M. R = 52
Q = 1·45 M. R = 35
Red Q = 0·15
Q = 2 M. R = 50
Atchafalaya Q = 0·5
Q = 1·5 MILLION CFT PER SEC.
ST FRANCIS BASIN
WHITE RIVER BASIN
YAZOO BASIN
TENSAS BASIN
SECTION
SHEWING HIGH AND LOW WATER
Q IS HIGH WATER DISCHARGE
R DIFFERENCE IN STAGES.
High Water Surface
Low Water Surface
300 MILES
100 M.
280 MILES
200 M.

THACKER, SPINK & CO., CALCUTTA.

raised." The effect, he says, so far seems to be divided between a higher surface and a lower bed.

After reviewing levels of the different stages from 1882 to 1894 he finds that for the years subsequent to 1890 the mean stage of low water was lower throughout the entire river below Cairo than in earlier years; and it will be observed further that "while the mean relative depression where no effective extension of the levee system is yet made, or from Cairo to Helena, is 2·89 feet, from the White to the Red River, where greater levee progress has been made, the depression is 4·46 feet, or 1·57 feet more."

Further, a comparison of the mean of low waters of years previous to 1891 with the low water of 1894 shows that while the relative depression in the latter year in the upper or unleveed part of the river was 4·88 feet, in the lower or leveed part it was 7·41 feet, or 2·53 feet more.

"The period during which the river has been the subject of observation and work is too short to give definite conclusions, but the tendency shown in the foregoing, and by other indications, is quite marked for the limited time considered."

Mr. Starling's views

Mr. Starling sneers at the idea that confining the waters of a river tends to cause a deposit of silt in the bed thereof. He speaks of it as opposed to sound reason and says it has been disproved a hundred times. The misstatement, however, seems to have taken a much firmer hold upon the popular mind than the refutation.

"Observation shows that, since the Mississippi has been confined between levees, its tendency has been rather to erode than to deposit, as has been demonstrated by caving banks. The best test of the condition of the bed is to be found in low water observations. At such stages the water surface conforms more closely than at any other to the bottom of the river. Now, in 1887, 1888, 1889, 1891 to 1895, since the levee system was made continuous below the mouth of the Arkansas, the river below Cairo was exceedingly low, and in the two years last named it went far below all previous records. That this was not due to paucity of water is shown by the gauging. For equal stages, each of these years exhibited an increase of low water discharge over its predecessors."

Finally, Mr. Starling remarks:—"It may be added that not one of the engineers who have written systematically upon the Missis-

sippi, from Charles Ellet and Humphreys and Abbot to the Mississippi River Commission, believes that levees have any tendency to deteriorate the bed of the river."

Results of special survey made by Mr. Ockerson.

A survey was made in November and December, 1894, of the river from the mouth of the Arkansas to Vicksburg, a distance of 200 miles, and a comparison of the various "elements of the regimen" was made with similar elements derived from the surveys of 1881 and 1882.

Sections of both surveys were plotted from the original notes and from a common datum line, in order to eliminate discrepancies incidental to plotting and measuring areas. In the later survey sections were taken at about 200 metres apart normal to the river and, in selecting for comparison, the one found nearest to the section of the previous survey was taken.

From Mr. Ockerson's report on the reduction of notes of this low water survey, printed as Appendix 10 B, page 3577, *et seq.*, of the Chief of Engineers' Report for 1896, it is apparent that very great care was observed in order to obtain correct results

The sections were divided into three parts, *viz.*, Low Water, or the stage when sounded in 1894; Medium Stage, being a stage corresponding to the mean of high and low water of 1882, as used in the "regimen elements"; and Bank Full Stage, which just reaches to the top of the local river bank proper and corresponds with the bank full stage of "regimen elements."

The areas and mean depths of the 554 coincident sections of the two surveys for these three stages were measured and computed separately, giving 554 results for each condition of stage. The results for the individual sections were tabulated in such a way as to show. for each section in both surveys, the elevation of water surface when sounded, the width, area, mean depth, and the maximum depth at low, medium, and bank full stages.

Then tables were compiled giving average cross-section elements of stretches, embracing successive pools and bars, for each of four reaches of the river; and finally a table was made giving the average cross section elements of each of the four reaches taken as a whole, and also the grand mean for all of the sections from Arkansas River to Vicksburg.

Mr. Ockerson gives a comparison of the elements of each reach; and, after a careful study of all the varying conditions which he enumerates in detail, he finally arrives at the following conclusions:

(1) The channel capacity in 1894 was greater than in 1881-1882, due largely to changes above the low water line.

(2) The crests of the shoal bars, in 1894, were, on the whole, lower than in 1881-1882. This refers to the actual elevation of the bottom and not to the depth of water on the bars.

(3) The maximum depth of pools was generally less in 1894 than in 1881-82.

(4) The thalweg depths were, on the whole, less in 1894 than in 1881-82,—that is, a little more than one-half on the length of the river under consideration and also the average of the sections show an elevation of the thalweg, or raising of the bottom. A large percentage of this raising occurs in the pools.

(5) The high water bars lying between the medium and bank full stages have been cut down an average of something over one foot.

(6) *The general tendency seems to be toward a channel more uniform in depth and of greater capacity.* (The italics are of the writer.)

As far as the writer has learnt the above is the strongest definite evidence, accurately and concisely recorded, of changes which have occurred in any considerable length of the river's channel. In the length under consideration the levees have been constructed and maintained successfully only during late years.

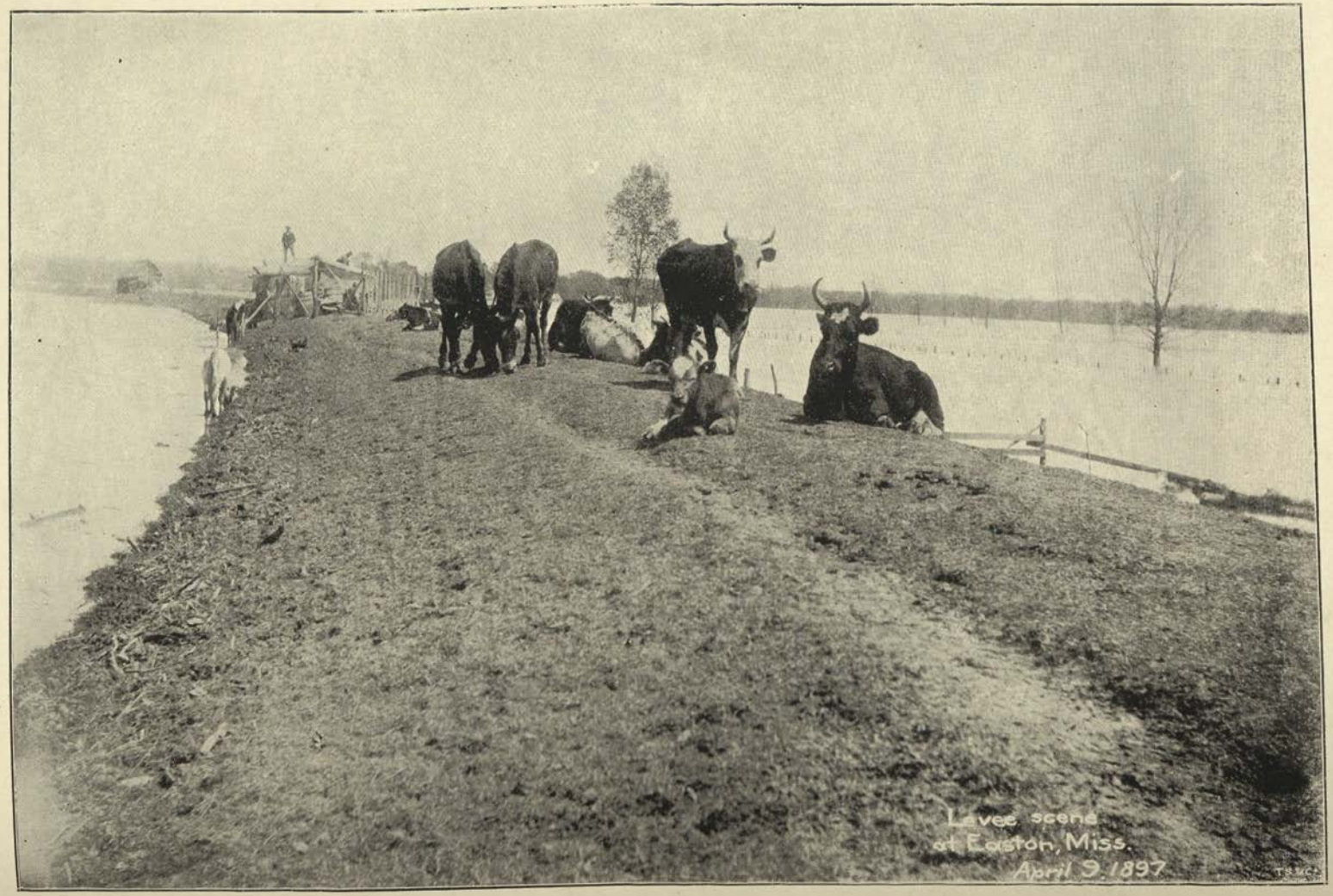
The final conclusions from all of the above may surely fairly be said to be as follows:—

Final conclusions by the writer

(1) The general effect of the construction of levees along the banks of a river is to improve its regimen, to deepen its bars, to level up its pools, and to increase the widths between banks; all tending to enable the river to discharge more of its water through its own channel. (Of course, during the progress of confinement by levees, the high stages of floods rise till a maximum due to confinement is reached.)

(2) After completion of the Levee System and during the approach of the river to its final state of equilibrium of bed and channel the levels of low, medium, and high stage waters are lowered, till, what may be called, "final" stages of each are reached.

(3) Then later, after equilibrium has been practically established, there may be a slight raising of the bed, due to the fall of surface being distributed over a slightly greater length of the river by the extension of the bar at its mouth further into the sea, but this rise in bed levels will probably not amount to more than a few inches in a hundred years.



Levee Scene at Easton, Miss., April 9, 1897.

CHAPTER V.

Floods and Prediction of Gauge Heights—Relation between Stage of River and Erosion or Fill of the Bed—Effects of "Cut-offs" on River Channels—Outlets.

FLOODS AND PREDICTION OF GAUGE HEIGHTS.

In his pamphlet on the floods of the Mississippi River, Mr. Starling devotes a chapter to the topography of the Basin, its climate, rainfall, flood period of the tributaries, influence of snowfall, storms, &c., on floods and flood heights; and he discusses the difficulty in the case of the Mississippi of estimating by any reliable method the probable gauge heights which floods will reach. His paper is sufficiently instructive to warrant a synopsis of it being produced here, in the hope that it will point to and assist in the proper study of the available data of the Indus River Basin, where the conditions are simpler owing to the absence of tributaries in the lower river and to the comparatively regular and limited times within which the Northern tributaries combine to swell the middle and lower river.

Topography.—"Of the immense territory which is drained by the Mississippi, a part belongs naturally to the Appalachian System, and a part to that of the Rocky Mountains. These two divisions are not very different in size. They are nearly as diverse as can be in their characteristics. One is rocky, the other earthy; one humid, the other dry; one naturally wooded, the other consisting almost wholly of prairie or plain; one geologically old, the other recent. These peculiarities exercise the most remarkable influence on the rainfall, the drainage and the quantity and the quality of the contributions to the main stream made by the tributaries passing through the respective portions of its basin. . . . . ."

"Perhaps the most natural and intelligible division of the Mississippi Basin is into an old and a new part. The Appalachian Ranges were upheaved at a very early period of geological time, and there has been no material elevation or subsidence of them since. The Rocky Mountains, in their present form, are the product of a very much later age. The Ohio and the Upper Mississippi were old rivers before the Missouri, as we now see it, had an existence. . . . ."

63807

"The boundary between the Appalachian and Rocky Mountains, or old and new portions of the Mississippi Basin, is not easily defined geographically, but may be said, without grave error, to lie along the 97th meridian, as far south as Red River, and as far north as Yankton or the mouth of the Niobrara. The old part embraces all the valley of the Ohio and of the Upper Mississippi, to within a short distance above Cairo, the lower part of the valley of the Missouri proper from a short distance above Omaha down, and of some of the Eastern tributaries of the Missouri, even higher up, and of a part of the Kansas and the whole Ozark region including the St. Francis and White Rivers and the lower part of the Arkansas. The new part comprehends everything else to the foot of the Rocky Mountains, with the Black Hills standing as an island in it. . . . . ."

Rainfall.—The climates of the two divisions are as different as their origin and physical constitution. "The great floods of the Ohio are usually early, coming occasionally in January, most commonly in February, seldom after March. There are not unfrequently, however, sharp freshets at later or earlier periods, which, while hardly to be called floods, are sufficient to co-operate powerfully with rises from the other tributaries. . . . . The rainfall in the valley of the Upper Mississippi is heaviest in May and June and least in December, January and February. Indeed, the river is usually frozen during these months, at least in the upper part of its course. . . . The principal floods of the Missouri take place in May and June. The same causes which operate here to produce the rain serve also to melt the snow. . . . . There are sometimes early spring rises in the Upper Missouri from the melting of snow alone, and there are often floods in the lower part of the valley from rains. A considerable part of the immense tract called the Missouri Valley lies within the belt of moderate rainfall—31 inches. Several important lower tributaries drain the slopes of the Ozark Mountains, a region of heavy precipitation, and it has occasionally happened that there was a pretty high stage at St. Louis in February or March . . . . That part of the floods of the Arkansas which originates in or near the Rocky Mountains has comparatively little effect upon the Mississippi. . . . . The main supply of water, so far as the Mississippi is concerned, from the streams of the Arkansas Basin, is derived from the slopes of the Ozark Hills and their continuations the Ouachita Ranges. The

discharge of the St. Francis, White and Arkansas Rivers combined is very little less than that of the Missouri. The Yazoo sometimes pours out a considerable volume of water, but as it empties rather low down, it is only of local importance. . . . ."

Flood Period of Tributaries.—As before noted, Mr. Starling divides the rivers which contribute to the Mississippi into the Eastern and Western systems. He remarks that it is possible for a very great flood in either to combine with an average stage in the other to produce very high water below the mouth of the Arkansas; but the usual order of floods for the several tributaries is as follows:—The Ohio, Cumberland and Tennessee altogether, then the Upper Mississippi with the Lower Missouri, then the Upper Missouri; the other Western rivers may accompany either or both of the two latter movements.

Influence of Snowfall and Rainfall upon Floods.—"It is often affirmed that the principal cause of floods is the melting of the winter's ice and snow. This opinion seems to have a strong hold on the popular mind, and is entertained even by many intelligent people. It is no doubt founded on the imposing and often observed phenomena of mountain streams. As applied to rivers, the greater part of whose course lies in the low lands, it may, without question, be pronounced erroneous. In the case of the Ohio, it is well known that some of the greatest floods ever recorded have occurred when there was little snow on the ground. On the other hand some of the heaviest snowfalls have disappeared by gradual thawing without rain, and made but a trifling and evanescent impression on the rivers. The most potent agent in producing floods has been excessive rainfall. In making this assertion, it is not intended to exclude the action of snow where it exists. On the contrary, the latter co-operates powerfully with the rain. A deep snow passing off with a warm and heavy rain of course greatly augments the effect of the latter, and that too at a very critical time. . . . . The heaviest, most sudden, most violent, most extensive and most dangerous rains that occur in the Mississippi Valley are those that accompany the cyclonic storms which sweep across the country from west to east in the winter, spring and summer months. These storms pursue several different tracks. They may originate either in the north-west or in the south-west, and may travel either due east along the lake region or along the Gulf

coast, or they may move diagonally up the Central Valley in a north-easterly direction. . . . . The most formidable storms, however, so far as rainfall and floods are concerned, are those which originate in the Gulf itself. They cannot usually be predicted by the observers of the Weather Bureau, because there are no meteorological stations in the Gulf. . . . The passage of one of these cyclones often occupies two or three days, and a rainfall of three inches is not unusual. A considerable flood has been known to result from two of them at an interval of about a week apart. The time was from the 26th of March to the 2nd of April 1886. There was little snow on the ground, and the rivers were decidedly low. . . . . ."

"There are two classes of floods which afflict the alluvial plain of the Mississippi; the early floods, which proceed mostly from the eastern rivers, and the late, which owe their origin principally to the western streams. The former usually reach their height in the lower valley in March, the latter in May or June. Sometimes there occur very high waters of a third class, intermediate between the two, in which a late rise from the Ohio meets an early freshet from the Upper Mississippi and Missouri accompanied as usual with heavy rises from the lower streams. Such floods culminate in April or May. . . . . ."

Forecasting floods and flood heights.

While recognising that it is a matter of the highest consequence to forecast the progress of a flood, and that this can best be done by comparison with past experience to trace an analogy from which to draw inferences, Mr. Starling says the study of the hydrographic curves of the Mississippi is on the whole very dissappointing. "As a rule, there is very little resemblance between the various floods of the Mississippi, even between those of the same origin. With a few exceptions, there is hardly any analogy to be traced between the hydrographs of any two floods at whatever interval."

He considers the possibility of drawing inferences of expected stages of the river from the rainfall in the several valleys, and he dwells considerably upon the complexity of the problem, the paucity of rainfall stations, the divergence between rainfall and run-off according to the length and intensity of the rainfall, the condition of the ground, season of the year, &c. Other considerations mentioned which affect the stage to be attained, especially in the

lower river, are the height at which the principal rise finds the river, duration of the rise, local rainfall in the lower river, rate of travel of the flood wave, which is dependent again on the stage of water, condition and extent of the levee system, basins available for spill, &c.

Further, the difficulty of the problem in the Mississippi has been rather increased of late years by the shutting out of the Yazoo, St. Francis and White River Basins, which were formerly open to spill from the river, and which thus acted as regulating reservoirs for great floods. The confinement of the river between levees has entirely altered the conditions, flood lines have been raised, flood waves pass more quickly than formerly, and the hydrographs of previous great floods from 1880 to 1890 are of but little assistance in the altered conditions of the present time.

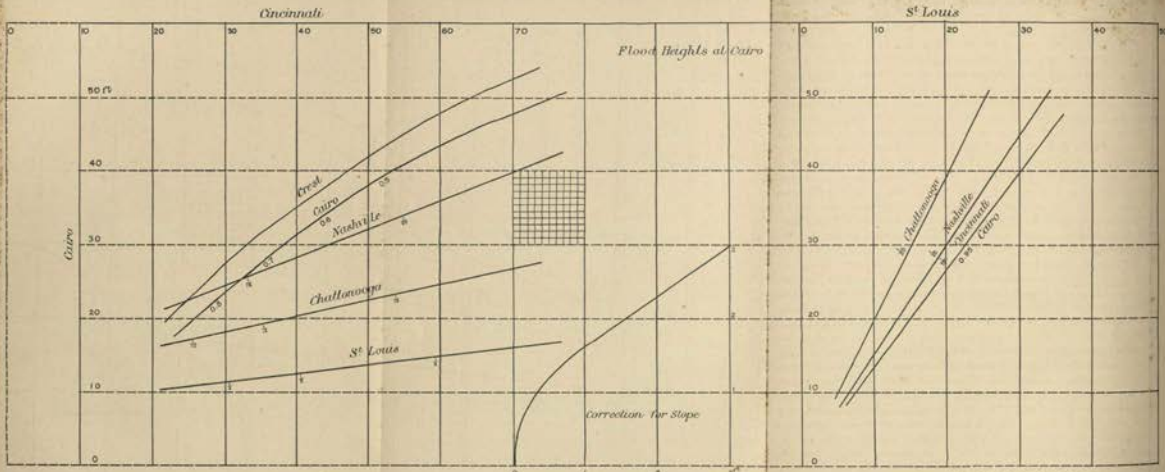
Method of computing expected Gauge Heights.—"Various attempts have been made to predict the gauge heights to be attained at the several stations from the reported rainfalls and also from the known volume of freshets in the tributaries themselves. For the former purpose, one method was to compute the number of cubic miles of rainfall in the several drainage basins, and then reduce them to run-off by an appropriate factor. This quantity was converted into discharge and this again into gauge height. It will easily be seen that the inexactitude of the data, and the imperfection of our knowledge of the relation between discharge and gauge, forbade accurate results from such a process. The best means of predicting the effect of a given rainfall in a certain locality is by observing the previous behaviour of the streams under circumstances as nearly as possible similar in season, stage and quantity. . . . . If the river is low or high, or if the season is far advanced, these modifying circumstances must receive due consideration. Long experience gives a good deal of facility and some sagacity in these matters; though the limited number of stations from which telegraphic reports are published precludes anything like accuracy. . . . . ."

"The system adopted by Professor Russell was based on the following proposition:—If there be a rise of a given number of feet at an upper station, then, first, the rise produced at a lower station from this source will be greater as the stage at the upper station is greater; second, the rise at the lower station will be greater as the stage at the lower station is less; third, the height to be

reached at the lower station for a given rise at that point will be greater as the stage is greater. Hence, the rise at the lower point, considered with reference to any one point above, is a function of three quantities: of the rise at the upper point, of the stage at that point, and of the stage at the lower point. Of the first two quantities, it is a direct, of the third an inverse function. It is assumed then that an expression can be found for the unknown quantity by multiplying the two known quantities together, and by a constant factor, and the sum by a variable factor, dependent on the stage at the lower station. If there were only one tributary to be considered, there would be no need of the constant, but the whole multiplication could be thrown upon the last factor. . . ."

Mr. Starling states that the levee engineer does not usually seek to formulate a rule, but compares the given circumstances with the experience of the past. A study of the hydrographs and the conditions prevailing enables the experienced engineer to guess approximately what to expect in his particular locality. In applying records of past observations to the purpose of deducing therefrom the probable stages to be attained by a flood just coming into sight, it is indispensable to have an accurate knowledge of the changes that have occurred and that are continually occurring in the lower river, especially in the levee extension. If instruction is to be derived from records of the past, it must be the result of careful study, conclusions drawn from such records are more of the nature of calculations in which the influencing factors are taken into consideration. "There are several methods which promise a hope of success in this way. If discharge observations have been systematically taken at any point, and a certain ratio of progression established between the discharge and the height of the gauge, then if the probable discharge can be predicted the flood height may become known. Again, if we can find any gauge which has not been subjected to disturbing influences, but has remained unaltered for many years, and if we can trace any parallelism or any known relation whatever between it and the gauges below, at stages less than the highest, then by analogy the relation may be extended to extreme heights."

"It is possible, from close observation of the rises in the great tributaries, or even from the reports of the rainfall, to make a pretty fair approximation of the stage to be reached at Cairo by any flood, and



LITHO BY THACKER, SPINK & CO. CALCUTTA.

the probable discharge can be estimated from the stage and from other circumstances. . . . . So far as any hope is concerned of deducing a regular relation between discharge and stage, they are extremely disappointing, for they are discrepant and apparently capricious beyond measure. . . . . "

"The relations between the several gauges have been made the subject of study by several engineers, particularly by Colonel Suter, Major Rossell and Captain Townsend, of the Corps of Engineers, U. S. Army, who have drawn from them many interesting and useful conclusions. As applied to the matter in hand, it may be said, roughly speaking, that under ordinary circumstances, with the St. Francis Basin open, a stage of say 48 feet at Cairo maintained for several days, with the Arkansas and White Rivers at a moderately low stage, corresponds to about 46·5 at Helena, 49 at Arkansas City, 44 at Greenville, and 48·5 at Vicksburg. Of course these figures are subject to modifications in all sorts of ways—by the behaviour of tributaries and reservoirs, by diversities of slope, by duration of flood and by other causes—all of which must be taken into account, if an estimate is to be accurate; and even half a foot is a matter of serious consequence at the top of a great flood."

Prediction of Floods.

Captain Townsend gave a good deal of consideration to the question of flood prediction on the river and obtained results such that he claimed to be able to determine the height of a flood at Cairo within 2 feet, or to know beforehand that his rule did not apply. His method of determining height was: To use the height a flood attained at Cairo as an ordinate and the height attained at Cincinnati as an abscissa, and, by plotting results for various floods of back years, he obtained points through which a mean curve was drawn called the "mean gauge relation between Cincinnati and Cairo." It is shown on the sketch, opposite, as "crest line." This curve is supposed to represent, for a given height at Cincinnati, the height that will be attained on the gauge at Cairo several days later, if normal conditions obtain, *i.e.*, if a certain slope exists in the river, proper heights at the different gauge stations, and the rivers rising at certain rates. If any of these conditions are not fulfilled the gauge at Cairo will be affected, and the problem then is, to determine the normal conditions and what corrections should be applied for variations.

To determine the slope, he takes the height of the gauge at Cairo on the day the crest passes Cincinnati, and finds whether, on the day the Cairo gauge falls on the curve marked Cairo, the crest of the flood tends to come on the line marked crest. If the height at Cairo does not conform to this line, the flood height will be greater or less than the normal by 5/10 of the difference if the gauge at Cairo exceeds 40 feet, and by 6/10 of the difference if between 30 and 40 feet. A second correction is for rate of rise; if the gauge at Cairo is rising about 6 inches a day, the condition is normal, but if a rapid rise is occurring, a correction is added, shown by the curve for rate at Cairo. To hold the flood at its normal height the rivers at Nashville, Chattanooga and St. Louis must be at a given height, which are shown by lines marked on the sketch. If these gauges do not stand at these heights, corrections are to be applied, but these corrections are affected by whether the river is rising or falling. The data is insufficient to determine all the numerical values. He therefore adopts the rule of omitting the correction if the gauge is higher and falling, or lower and rising. In other cases, the proportion of the difference, as indicated on the lines, is added or subtracted as the case may be. A few of the results obtained by applying these curves to the floods that have passed Cincinnati with a height exceeding 40 feet are shown in an appended table. For heights less than 40 feet at Cincinnati, dangerous floods need not be anticipated from the Ohio.

There are, however, certain exceptions to these rules to be considered, *viz.:* (1) If at Cincinnati the river has been falling within six days of the rise, the Cairo gauge does not indicate the slope properly and the error may be 3 feet. (2) If on the day the crest passes Cincinnati the Cairo gauge is falling, the correction for rise of gauge will be incorrect. (3) Floods not yet having manifested themselves at St. Louis and Nashville may, within the next three days, cause a sudden rise at Cairo. This will be indicated by heavy rainfalls or by rapid rises of the rivers above these locations. In this case, predictions can be made only three days before the flood reaches Cairo. A second set of curves is added to the diagram to solve these conditions.

In this case the curves develope into right lines, the crest parallel to the Cairo line and 2 feet above. The line of normal height

at Cincinnati appears to coincide with the Cairo line. The readings of the Cincinnati and Chattanooga gauges are to be taken three days before those at St. Louis and Nashville, and the reading of the Cairo gauge used as ordinate. A second table shows a few of the results of applying these curves to floods exceeding 25 feet at St. Louis.

In illustration of the application of his method Captain Townsend works out the first example on each table thus :—A flood height of 71·1 at Cincinnati gives a mean height at Cairo of 52·6, but in order for this to result the Cairo gauge on the same day should have read 47·6, St. Louis 16·4, Chattanooga 26·2, Nashville 40·1, and the rate of rise at Cairo should have been 0·4 of a foot. Cairo standing 48·2, $0{\cdot}6 \times 0{\cdot}5 = 0{\cdot}3$ is to be added to 52·6. St. Louis standing 14·3 and falling, $\frac{1}{6}$th $(16{\cdot}4—14{\cdot}3) = 0{\cdot}4$ is to be subtracted. While both Nashville and Chattanooga are below their normal readings, as the gauges are both rising, no correction is applied. The rate of rise at Cairo being 0·8 of a foot per day 0·2 is added, giving 52·7 as the height computed. The actual height attained was 51·8, difference $+0{\cdot}9$. A flood of 36 feet passing St. Louis, Cairo should stand at 2 feet above 47·5 three days after, under normal conditions, but the gauge at Cairo on the same day reading 43·1, 95 % of $4{\cdot}4 = 4{\cdot}2$, should be subtracted. For 43·1 ft. at Cairo, Cincinnati should stand at 32·1, being less than that and rising, no correction is added. Chattanooga stands at 5·2 falling, instead of 21·6 the normal, and the correction is $\frac{1}{20}$ of 16·4 or —0·8. Nashville is below the normal and rising and requires no correction. The rate of rise of 0·6 instead of 0·4 requires a correction of + 0·1, giving $49{\cdot}5 - 4{\cdot}2 - 0 - 0{\cdot}8 - 0 + 0{\cdot}1 = 44{\cdot}6$, as the computed flood height at Cairo ; the actual is 45·1, difference $-0{\cdot}5$.

Captain Townsend states that, while this method of predicting flood heights is admittedly crude, it gives better results than any that has been suggested heretofore. By further analysis it is susceptible of still further development, etc.

TABLE I.—*Floods from Ohio River.*

Date.	Cin.	Cairo.	St. L.	Chat.	Nash.	Rate of		Corrections.	Computed.	Actual.	Diff.	Remarks.
						Rise.	Mean.					
14/2/84	71·1	48·2	14·3 -	9·4 +	22·0 +	8 +	52·6	+ 0·3 - 0·4 + 0 + 0 + 0·2	52·7	51·8	+ 0 9	.....
15/2/83	66·3	43 3	10·3 +	14·4 +	41·5 +	2·0 +	51·1	- 1·2 + 0 + 0 + 2 + 1·7	51·8	51·8	- 0	.....
25/3/90	58·9	46·6	12·2 +	8·15	18·0 -	·0	47·4	+ 2·0 · + 0 - 1·0 + 0 - 0·1	48·3	48·2	+ 0·1	Crest 48·6 five days after.
21/2/82	58·6	47·4	27·5 -	15·5 -	38·3 +	2·1 +	47·2	+ 2·5 + 0 - 0·5 + 0·1 + 1·8	51·1	51·9	- 0·8	.....
25/2/91	57·3	44·3	11·0 +	29·0 +	25·9 +	·4 +	46·1	+ 1·2 + 0 + 0·4 + 0 + 0	48·0	46·2	+ 1·8	.....

TABLE II.—*Floods from Mississippi and Cumberland River.*

Date.	Cin.	Cairo.	St. L.	Chat.	Nash.	Rate of		Corrections.	Computed.	Actual.	Diff.	Remarks.
						Rise.	Mean.					
19/5/92	36·0	43·1	22·0 +	5·2 -	11·8 +	·6 +	45·3	- 0 - ·8 + 0 + ·1	44·6	45·1	- 0·5	.....
26/6/83	34·8	39·2	21·3 -	3·5 -	4·4S	0	41·5	- ·5 - ·9 - ·1 - ·1	39·9	39·1	+ 0·8	.....
5/6/92	34 8	43·8	28·5 -	5·4S	12·6 -	3 -	45·9	- ·3 - ·9 - ·7 - ·1	43·9	44·0	+ 0·1	.....
5/5/81	33·6	41·7	20·1 -	6·5 -	12·9 +	3 +	43·5	- ·8 - ·7 - 0 - 0	42·0	42·6	- 0·6	.....
6/7/82	32·2	37·7	25·0S	6·0S	9·8S	1·7 +	39·2	+ 0 - 7 - ·6 + 1·3	39·2	38·8	+ 0·4	.....

RELATION BETWEEN STAGE OF RIVER AND EROSION OR FILL OF THE BED.

An interesting report on an investigation of the relations existing between stage of river and the scour or fill which takes place in the bed was made by Mr. Ockerson in April 1896. (See Chief of Engineer's report for that year.) He premised his report by these remarks: "Much difference of opinion exists as to the time and conditions of stage when the deposits are made and the low water channels are obliterated; also when and at what phase of the stage the scouring out actively begins which finally results in a renewal of the low water channels. With a view to reaching some definite conclusions on this subject plates 1 to 6 have been prepared, showing the gauge curves and the mean and maximum depths for equivalent dates." The data for his plates are found in results of discharge observation which covered considerable periods of time and were made at eleven different stations.

Altogether he discusses 201 phases of stage. Of this number there are 66 cases where the mean depth increases or scours on a rising stage, and 83 cases where the mean depth decreases or fills on a falling stage. There are 61 cases where the maximum depth increases or scours with rising stage, and 79 cases where the maximum depth decreases or fills on a falling stage. It is noticed that the scour incident to rising stages is prolonged somewhat, and the crest of the rise and fill continues beyond the minimum stage reached by the fall.

The observations do not extend far enough into the low water periods to disclose the condition under which low water scour takes place. It is probable that the phenomena of scouring bars at low water, noticed by pilots and others, are confined to the crossings and are merely local not general conditions.

Mr. Ockerson remarks:—"It is probable that the relations found at the discharge sections apply also to crossings. The rising stages are accompanied by increasing velocity and should produce a scouring effect. Falling stages are accompanied by decreasing velocities and fill is a necessary consequence. These phenomena are doubtless common to the whole bed." (He apparently neglects the result of

change of direction of the main current of the channel during rise and fall of stage, and the consequent lateral movement of the thalweg on crossings. His conclusions are not necessarily correct regarding the crossings. The low water crossing during the rise in stage from low to high water may be left to one side of the highest velocities of the changing discharge area, resulting in a fill on the low water crossing during the rising stage. This fill has then to be scoured out on the falling stages as the current reverts to its former position on the concave sides of the bends.)

In addition to the general change of stage, crossings are affected at low water by increased velocity due to local change of stage—that is to say, the bar acting as a dam developes an abnormal slope between the pools when the volume of flowing water becomes small. This excessive slope with its increase of velocity soon begins the scour on the crossing. The local water surface is lowered, and the deposit left by the falling stage is again taken up.

Finally, he concludes: "In examining the diagrams it will be seen that there are many minor oscillations in depth which do not seem to conform to changes in stage. These are largely sand waves. It may be said, however, that *nearly every rise of considerable magnitude and duration is accompanied by scour, and a similar fall is accompanied by a fill.*"

The value to be placed on the above investigations depends largely on the location of the gauging stations with reference to crossings and pools. Mr. Ockerson, however, informed the writer that most of the stations are suitably situated for discharge measurements, that is, they are in comparatively straight reaches and fairly free from disturbing influences of changing crossings, etc. He pointed out the advisability of a special investigation of changes occurring in both pools and crossings in order to obtain correct conclusions regarding the effect of rising and falling stages on each.

EFFECTS OF "CUT-OFFS" ON RIVER CHANNELS.

A "CUT-OFF" in a river channel shortens its length and causes a redistribution of the slope and accelerated velocity in the reaches adjoining the cut-off, which extend up and down stream for considerable distances. It is accompanied by a lowering of the water surface as the volume of water is discharged through a lesser cross-section than under the original conditions, and a cut-off therefore affords relief to the levee lines along and adjoining the reach of river in which it occurs. This, however, is only temporary, for the increase in velocity causes erosion and lengthening out of bends, and consequent lengthening of the river, which, in the course of time, regains its original length.

Mr. Starling on "Cut-offs."

In support of the belief that the beds of sedimentary rivers are self-regulating, and, in the case of the Mississippi, that between the fixed points (the slipping off place above Cairo at the head of the alluvial valley, and the Gulf level) it must have a fixed slope, Mr. Starling says: "If it does surpass this limit it becomes destructive, and erosion ensues until, by the lengthening of bends thus produced, the slope and velocity are lessened. In 1876 a cut-off occurred at Vicksburg whereby the river was shortened about 6·5 miles. In 1892 a survey showed that in a distance of about 50 miles above the cut-off and as many below, the river had regained about 4 miles."

Further he quotes the distance from the mouth of the Ohio to New Orleans in 1821, according to surveys of the three previous years, at 954 miles, while in 1882 it was 963 miles. Then "in 1884 occurred the waterproof cut-off, shortening the river about 12½ miles, and allowing for subsequent lengthening of bends, it is likely that the distance now is very nearly the same that it was in 1825. Yet, within the interval of 72 years there have occurred, at least, 14 cut-offs, with a shortening of, at least, 160 miles or so."

He considers them altogether out of place on the rapid and unstable Mississippi. "They produce violent changes of regimen, tearing away valuable plantations and destroying costly lines of levee

on the one hand, and condemning considerable towns to decay on the other, by leaving behind them extensive sand bars or unnavigable channels; and all without accomplishing any good purpose."

Cut-offs proposed by Mr. Pharr in 1897.

It will be seen by perusal of page 3,546 of Chief of Engineers' Report for 1897, that Mr. Pharr, Chief Engineer, Lower St. Francis Front, proposed no less than three cut-offs between Helena and Vicksburg, to "remedy" the want of slope in that length of the river, "by reducing its length more than 40 miles, thereby increasing the slope and reducing the high water line along that reach of the river, so far as to make their present levees sufficient for any flood." This recommendation was made in the interests of the St. Francis' Levees, after reviewing at some considerable length the relations between gauge heights reached by the 1897 flood, but it did not meet with approval of the Commission.

Curiously enough, the length in which these cut-offs are proposed is above the reach of most active erosion referred to under the head of "Erosion" in these notes, and above the reach, when considered in short lengths, of least slope in the first 650 miles of the river below Cairo.

General opinion.

The general opinion seems to be, as stated by Mr. Starling, that "cut-offs" merely disturb the equilibrium of the river, and are objectionable on the Mississippi.

Prevention of Cut-offs.

The action of the Mississippi River Commission in their treatment of Ashbrook Neck, 446 miles below Cairo, indicates their opinion of the effect of cut-offs and the advisability in certain cases of their prevention. The following extract from the report of the Commission for 1896 speaks for itself:—

"Third District. . . First. . . . . Second. Ashbrook Neck, 446 miles below Cairo. This work is being done under the appropriation for the general improvement of the Mississippi River, and furnishes illustration of a second class of work where the prevention of the caving of the bank by revetment is the only practicable method. Between Offutts and Craig's Landings the course of the river known as 'The Bends,' is 40 miles long, while these points, in a direct line, are only 11 miles apart. In its sinuous course the river makes four long points across which the distance is from 2,300 to about 7,500 feet. Around each is about 10 miles. It is quite evident that should the river break through any of these narrow

'necks,' the reduction of length and increase of slope would so accelerate the current that the more rapid caving of the bank would soon eat through the others. So great a change in the regimen of the river would extend for long distances above and below, and injuriously affect the established condition of levees, harbours and navigation.

"Apprehending such a catastrophe the Commission in 1890 undertook the revetment of the upper bank of Ashbrook Neck. During that and the following working seasons 10,175 linear feet of bank were protected. This work has required but slight repair, and is now in good order. It has arrested the caving where applied, but it is considered advisable that an upstream extension of about 2,000 feet should be made for the complete protection of this bend. . . ."

Cut-offs on the Indus.

In the writer's opinion they are objectionable also on the Indus, excepting, perhaps, on a minor outlet or "Pass" to the sea below the limit of levees and regular cultivation.

The only instance, as far as is known to the writer, where such a cut has been artificially made on the Indus was to shorten the Uchito outlet for the purpose of obtaining a better supply of fresh water for Keti Bunder four years ago. What the result has been the writer is not aware of; but, if more than merely temporary, and if any large quantity of water has been induced down the Uchito, it has probably been to the detriment of the Hyderi or main outlet to the sea.

It is undoubtedly very necessary to consider the probable results of such cut-offs even on minor outlets near the sea before undertaking their execution. They will probably only temporarily improve the local conditions, or if permanent will unquestionably affect the discharges through other mouths.

OUTLETS.

THE term "Outlet" is applied on the Mississippi to large channels in or near the delta which diverge from the main river and deliver into the sea, really secondary mouths; to lateral escapes which spill over the natural banks into depressions or basins; to artificial escapes to discharge in the same manner; and to crevasses through levees.

Outlets have been proposed at different times as a means of reducing flood heights, but as waste basins are not available for the reception of such volumes as would have to be withdrawn from the river to give appreciable relief, the only location for artificial outlets or escape channels on the Mississippi would be in the delta reaches where they would deliver direct into the sea. The opening of such an outlet means practically the excavation of a new mouth or canal to the Gulf. Besides the first cost, that of its maintenance has to be considered, and also the effect it would have on the main mouth of the river. The latter, in the case of the Mississippi, is a very important matter, for the trade interests demand a depth over bars from the Gulf into the river and up it to New Orleans sufficient for sea-going vessels.

Captain Powell's investigation into effects of outlets.

During the time Captain Powell held charge of the office of Secretary of the Commission, he instituted an investigation of the effect of outlets on the bed of the river below them and later, having added some data, he made a report on the results of his investigation. (*See* Chief of Engineers' Report, 1891, Part 6.)

He had at his disposal records and reports from which were obtained reliable and comparable measurements of the river sections near and below outlets; and his investigation covers measurements of sections below outlets at different heights and conditions of river stage.

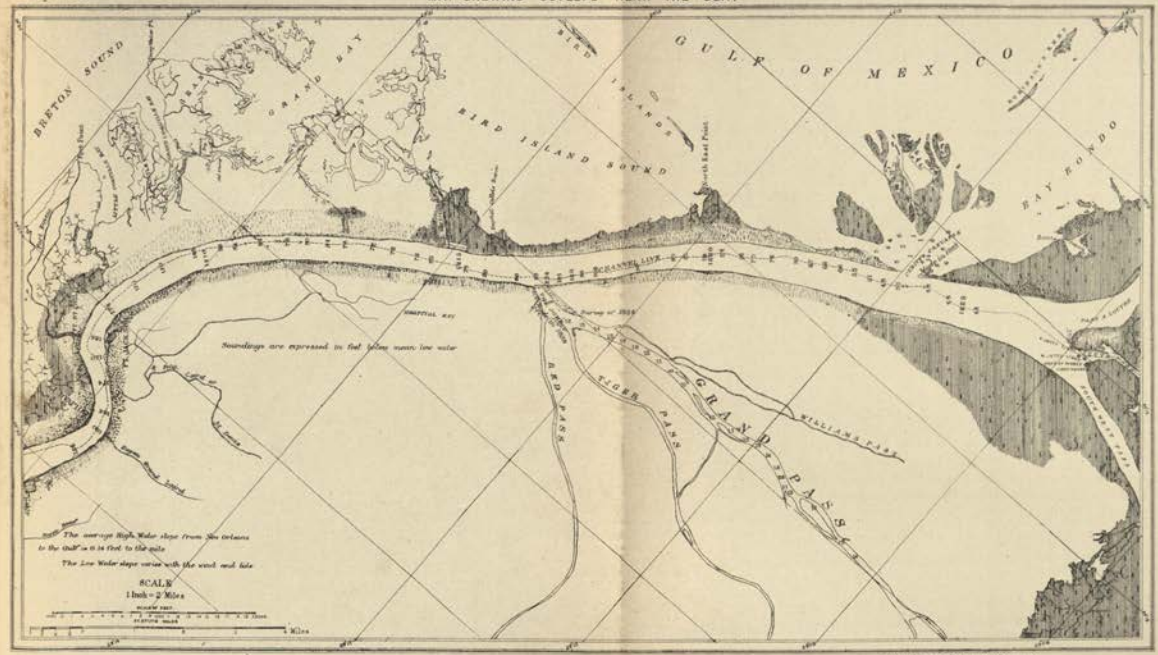
Preliminary investigations were also made into several side issues of interest which are mentioned in the preface of his report. His conclusions are extracted as below:—

"Judging that . . . effects of stage might mask the outlet effects, and if known furnish a key to the mystery of discrepant results, . . .

Map No XI

MISSISSIPPI RIVER.

MAP SHEWING OUTLETS NEAR THE SEA.



LITHO TRACKER, SPINK & CO., CALCUTTA.

Head of South Pass. Mississippi River, Dec. 12, 1898.

an examination was made of the effects of river stage at the discharge sections from Cairo to Carrollton, removed from outlet influence.

"This examination showed by means of plots, and in a decided way, that at the discharge sections named *a generally rising river scours the bed* and a generally *falling river fills it.*

"That the rising Mississippi, with increased velocity and volume and hence greater energy, should scour, and that the receding flood, when velocity is diminishing, should deposit from its heavy load of sediment, is an equally good theory to the generally accepted one of fill below an open outlet and of scour below a closed one."

He gave it as his opinion that while floods caused deposits they are made on the receding stage and to its lowest points and not on the advancing stage; and that the cutting out of bar channels across shoal places at low and falling stages should not be considered a proper exception to the general law indicated; neither should the case where the shifting of the thalweg on a rising river acts to temporarily mould a new form of section.

Another side examination made was to see the effect of crevasses on controlling depths in the reaches of the river lower down. He found from the data that while the fills in the pools were decided, the crevasses had but little effect on the depths of the crossings.

"Another deceptive conclusion as to outlet effects on the river bed has been drawn from comparison of sections above and below outlets, wherein the lower sections were found to be smaller and were made to apply particularly to outlets making from bends."

His observations of a number of curved reaches removed from the influence of outlets showed the same conditions existed in the majority of cases; the larger section was found at the head of a bend and the smaller at the lower end.

"The theory of fills below outlets is derived from the fact of the lowering of the water surface at the outlet, and consequently the loss of slope and velocity below. A gain of slope and velocity above must be likewise acknowledged; a scouring effect results thereby; and the comparison of sections above and below . . . . . does not show how much of the difference is due to scour at one section or fill at the other. Therefore to give a proper measure of outlet effects sections below the outlets only should be compared together."

With this preface he proceeds to compare results and to analyze them. On the Morganza Crevasse eight sections were available for previous years from 1883 to 1889, covering about five miles of river. After comparing results of his surveys with these he concludes: "On the whole, and from a consideration of all the measurements, the only conclusion which seems warranted by the record for Morganza is that the influence of river stage greatly predominates over the outlet effect, and masks the latter so closely that neither its amount nor direction can be stated."

Bonnet Carre Crevasse.—His conclusion, after analysis of results on this crevasse, was: "On the whole, and considering all the observations, a conclusion for Bonnet Carre similar to that drawn for Morganza, although less in degree, seems proper."

Cubitt's Gap.—Through this Gap the water flowed as through an orifice on to a flat of the Gulf. It formed a delta of its own. He found: "The tables show a very marked decrease of waterway of the main river below the Gap after it opened, as compared with the single survey made several years before the opening, for which no explanation is suggested other than the outlet influence. Cubitt's Gap appears to be a case where the fill on the river bed as an effect of the outlet considerably exceeded any opposing action of scour by rising stage of the river."

Atchafalaya mouth.

Next he considered the Atchafalaya which he says should be considered not only as a river channel, but the whole basin should be taken as an outlet for high water escape. He points out its conditions are different from the others, for owing to the construction of levees along it and the Red River of late years, it has received Mississippi water during the lower stages and only in an intermittent way during other stages. Here too a shoaling, though not great, was found below the outlet which was not explained by scour on a rising stage and deposit on a falling one. Other causes, he says, had more effect in this case. He concludes: "While it may not be safe to base any general law on the effect of the Atchafalaya outlet, it can be said that the filling of the main river bed below is not fully or satisfactorily referred to other cause."

Reviewing all of the above: "It may be noticed for outlets at and below Red River, from where they can be led directly to the Gulf, that, as far the record goes, the large all-stage outlet was found

to cause a measurable and remaining fill in the main river below, but not the smaller and high stage crevasse. When the latter ceases to flow, the effect of the river is by scour to return to its normal section of bed; and the action of 10 to 20% of the whole river for about one-fourth of the time ought not to decidedly influence it for the whole time."

Colonel Suter's Investigations.

In the same year Colonel Suter, Corps of Engineers, made a special investigation and wrote a paper on the crevasses which occurred below Red River. (See page 3,444 of Chief of Engineer's Report for 1891). He used what is called the method of "gauge relations" and produced a number of diagrams which are attached to his paper showing the relation between different gauge stations. The object of his inquiry was to find what heights the river would have attained had crevasses not occurred. His method of deduction is both interesting and instructive.

He computes that: "The Nita" crevasse which occurred at a point four miles above College Point, 900 miles below Cairo, while acting alone and with estimated discharge of from 300,000 to 400,000 cubic feet per second, lowered the levels which the river would otherwise have reached at College Point $3\frac{1}{2}$ feet; at Carrollton, 50 miles below, 2·15 feet; at Plaquemine, 45 miles upstream, 1·9 feet; at Baton Rouge, 68 miles upstream, 1·4 feet; and at Bayou Sara, 100 miles upstream, 0·2 feet.

This crevasse was, however, an exceptionally large one, and its effects were far more extensive than usual.

Mr. Starling on this question.

In an article on this subject Mr. Starling discounts the amount of lowering of floods supposed to be given by the occurrence of a crevasse, and argues with reason that it is much more local than is popularly supposed.

Then as regards outlets to deliver into the sea, he makes quotations from his notes on the Holland Dikes on which, after an extensive inspection, he read a paper before the American Society in 1892. He says: "The Dutch experience with outlets is all against them. The outlets were dangerous and detrimental on two grounds: they caused a slackening of the current, and consequently deposit and shallowing; by the same slackening the movement of ice was impeded and gorges formed. The principle is now utterly condemned." And so on.

He states in effect that the lowering of the flood water by a large outlet near the mouth seems to possess a great attraction for the public, but that the short channel to the Gulf would not reduce the flood height in the lower reaches, though it is even claimed its effect would extend to nearly the whole upper river. As to the latter claim he refers to the great Nita crevasse of 1890, the effects of which are detailed above, and he points out that they did not extend much beyond Bayou Sara 100 miles up the river. Then further, he points out that the influence of the outlet, if it developed upwards, would after a term of years, have the same consequences as a cut-off, that is increased velocity with bank erosion and lengthening of the bends until a condition of stability was again reached. In other words, "that would occur which is least to be desired, namely, a condition of chaos."

Though admitting that the flood line in reaches near the outlet would be lowered for a time, he denies that it would be permanent. "The best results that could happen would be for the outlet to close itself again. If it did not, it would become the principal mouth of the river or it would deteriorate and eventually ruin the old mouth, in either case utterly reversing existing conditions and undoing the good work of many years of both nature and man."

Opinion of the Mississippi Commission.

That the Mississippi Commission Engineers have held the same opinion for many years is evidenced from their remarks on the Atchafalaya as an outlet when considering what is known as the Red River and Atchafalaya rectification. The Atchafalaya, as stated by Capt. Powell, at certain stages does not act as a tributary bringing water into the Mississippi, but at the higher stages of floods takes water from it and discharges it into the Gulf through bayous and lakes.

In 1884 while presenting the above-mentioned project, the Commission remarked: "This leads to the consideration of the Atchafalaya as an outlet and to the question of its closure or restriction as such. The Commission entertains no doubt of the truth of the general proposition frequently heretofore stated, that the tendency of an outlet of substantial discharge is to impair the efficiency of the main channel below it. The complete closure of the Tensas Front (by levees) will transfer the discharge of the present outlet along that front to the mouth of the old river and the space between that

Near the Mouth of South Pass, looking toward Gulf. Dec. 12, 1898.

point and the foot of the Tensas levees. That the tendency of a permanent outlet so large and so sharply localized will be to impair the main channel below seems certain."

Mississippi Commission in 1893.

Again in 1893 the Commission incidentally recorded their opinion on outlets when dealing with the question of increased flood heights due to extension and completion of the levee system. They remark, page 3,560 of their report for 1893:—

"Undoubtedly greater heights will occur when a still larger proportion of high water discharge is controlled between levees, and when abnormal floods occur, but in the meantime the improvement of the levees undertaken and approaching completion . . . brings in sight a condition of the levee system that will give substantial relief and protection in all except years of unusual flood. . . .

"To any other system for the protection of these alluvial lands, there are objections, both theoretical and practical, which cannot be overcome. Those of a theoretical character are connected with the hydraulic law that a *reduction of flood discharge in a silt formed channel will reduce its capacity below the point of outlet.*

"This observation has been repeated in the many local comparative surveys of the river bed made by the Commission before and after crevasses, or before and after rebuilding the levee made necessary by a crevasse. The difficulties of a practical nature consist of the necessity of continuing any outlet to the Gulf without return to the river at any intermediate point. Such return would merely transfer the danger from one locality to another lower down. The condition thus imposed upon any outlet involves great cost and danger. Any outlet intended to relieve the parts of the river where flood heights are now most dangerous would, in any case, be very long. To have an appreciable effect it would require an excavated channel of large width and depth. . . . The cost of the levees which would be required to control it and prevent the permanent continuation of disaster and overflow while flowing through regions which will, in a few years, be placed under the sufficient protection of a levee system would be very much greater.

"When completed there would be two or more rivers, each presenting the same dangers and requiring the same treatment as the present single channel. The cost of efficient outlets would be greater

than the cost of completion of the levee system. When constructed, they would either silt up as do many Island Chutes, or would enlarge and assume the tortuous type of an alluvial stream with shifting bars and caving banks. Finally, conceived and executed in defiance of physical law, they would fail as a safe, cheap or efficient method of abating overflow.

"After a review of the progress thus far made in the improvement of a levee system and of the *facts developed by* the continued *surveys, gaugings and observations of the river,* such as *the entire absence of evidence of any rise of the bed of the river,* the local tendency to shoal where volume is reduced, and the larger discharge now controlled between levees, with an increase of flood heights which does not affect the practicability of a low system, *the Commission expresses its* continued *confidence in the reclamation* from overflow *of the alluvial lands of the* Lower Mississippi *Valley on the lines* now *proposed and in progress as entirely practicable,* at a cost which is amply justified by the importance of the undertaking."

CHAPTER VI.

Introductory Remarks on River Improvements—Bank Revetment—Continuous Revetment—Discontinuous or Detached Revetment—Bank Heads, Missouri River.

INTRODUCTORY REMARKS ON RIVER IMPROVEMENTS.

THE different methods employed in improving rivers for navigation purposes, and of which examples are found in North America, may be classed as follows :—

(1) Removal of snags, wrecks, and boulders, &c., obstructing the channel.

(2) Protection of banks against erosion, thus fixing the channel in concave bends and lessening the material which goes to make up bars;

(3) Construction of dikes, wing dams and training walls;

(4) Dredging, assisted on rock bars by blasting;

(5) Slackening water for navigation; and

(6) Construction of lateral canals.

The results obtained from bank protection are largely dependent on the character of the bottom and the description of the work itself. As will be shown, continuous revetment is being successfully built of a description suited to the conditions prevailing on the Lower Mississippi, than which no worse can be conceived, but the cost of this form of protection is so great that its use is limited to the holding of specially important lengths.

In alluvial rivers the effect of permeable dikes is shown after the first high water, the channel being deepened and accretions being built up often to highest flood level outside the limits of the contracted channel; but to be permanent, these accretions require revetments, or the dike system must be maintained. On tributaries and rivers with hard bottoms, the object of confining the channel is usually to raise the water surface and to obtain a better distribution of the slope over shallows and bars at low water. There is always a certain amount of danger in interfering with the established regimen of a river, and

although wing dams and training walls give increased depths in their vicinity, they often result in a tendency to cause shoals lower down. Special care is necessary in their alignment to bring the high water forces to bear on these points to scour out bars left in the low water season.

Dredging in hard material is generally a permanent improvement to the river, but in soft bars of recent deposit, especially in alluvial rivers, is more or less temporary.

Good examples of improvements by slackening water for navigation and by the construction of lateral canals are seen on the St. Lawrence and Lake Canals, and many other systems in this country.

Such works can be made perfectly successful, the only question for consideration being, as a rule, the financial one as to whether the advantages to be gained are commensurate with the cost involved.

Caving Bank, Caruthersville, Mo. Dec. 1898.

BANK REVETMENT.

The general plan of improvements of the Mississippi River originally provided for improvement of its navigation by the concentration of the discharge of the river at all stages within a well-defined channel by means of levees, bank revetments, and contraction works; and, at the present time, to satisfy immediate requirements, it also includes the deepening of the low water channels over bars by dredging.

Effect on Channels.

While there has been some difference of opinion regarding the extent of beneficial effect on the channel resulting from the construction of levees, there has also been similar difference of opinion regarding the effect of bank revetments. Indeed Mr. Eads strongly opposed them; *firstly,* because he did not believe they would be effective, and *secondly,* because of the enormous expense they involved and the impossibility (he contended) of maintaining them. The advocates of revetments, however, argue that by preventing the caving of banks, the supply of materials for building up shoals below is largely reduced and navigation is thereby improved.

The fact remains that the Mississippi Commission, who have given this matter special consideration, have steadily continued the construction of bank revetment on a very large scale until quite recent years; and at the present time they maintain the revetted reaches and construct new lengths where the interests involved demand it.

The opinion expressed by the Senate Committee last December, to the effect that "in view of the great cost, comparatively great taking into consideration the results, it would be more judicious to limit revetment to levee and harbour protection," may tend to limit expenditure on general bank revetment in future, as will also probably the great success being met with in the use of powerful hydraulic dredges to keep open and deepen low water channels. But a discussion of the merits of bank revetments as a means of channel improvement hardly comes within the scope of these notes, and will not be proceeded with.

There is no doubt though that revetments on the Mississippi have reached a high state of efficiency, and that such works are unquestionably useful in protecting valuable property and sometimes

in resisting threatened cut-offs or undesirable changes in the regimen of the river. The development in the construction of revetments and the methods followed of late years may therefore be briefly described with advantage.

When the Commission first undertook the construction of revetments on a large scale in 1882, they estimated their cost at about twelve dollars per running foot of bank. The earlier work, though on an extensive scale, was however largely experimental, and it was soon discovered that permanence could not be secured without the use of stronger and costlier structures, until at the present time the rate is as high as $30 to $35 per running foot.

Every feature has been the subject of experiment. The strength of materials used, manner of construction, width and thickness of the mattress, method of laying it in place, amount and disposition of the stone, &c., have all been experimented with and results carefully recorded and reported upon. And it is now stated, probably correctly, that the art of bank protection by subaqueous mattress revetment and rip-rap has reached a degree of perfection in the hands of the United States Engineers, who have had charge of the works on the Lower Mississippi, which has never been equalled elsewhere in the world.

Mr. Coppee on Bank Revetments.

Mr. Coppee, in his paper on Bank Revetment, traces the progress made on the Lower Mississippi from the earliest days as derived from personal knowledge and from reports of the Chief of Engineers. In his introduction he states that his object is to give in logical sequence the operations of the Engineers on the Mississippi River in dealing with the problem of bank protection; and that though much valuable engineering knowledge is buried in the executive documents, it can be resurrected only with great difficulty, as the different members of one subject have been often interred in many volumes covering a range of years.

The writer will, therefore, endeavour to compress and extract from Mr. Coppee's interesting paper sufficient information to follow the progress made in methods of construction which have led up to those approved at the present time.

Object of Revetment.

"The purpose of the revetment is to prevent the bank caving (which, without protection, is constantly occurring on the concave side of the river), and thus reduce the load of sediment carried to the bar preventing its rapid growth;

to maintain a normal width and depth in the bends, and to protect valuable property in danger of being destroyed by the constant action of the currents."

The lower river flows through a low-lying country subject to inundation, composed for the most part of sedimentary deposits, though undoubtedly having its origin in places at a period antecedent to the existence of the river. The material in the banks is generally in horizontal strata of varying thickness and consistency without definite order, the position of the layers being determined by the locality and its relation to the current during formation.

"The object has been to endeavour to construct all revetments sufficiently strong to protect the weakest material. The position of the strata and the drainage of the back-lying lands are also potent factors in the problem of improvement by revetment, as the lighter strata, sand, &c., act as drains for the ground water at low stages, causing much damage by sloughings."

For the purpose of these notes it will be convenient to consider revetments under two heads, *viz.*, Continuous Revetments, such as have been adopted generally in the upper reaches, and Discontinuous Revetments or Spur Dikes, commonly used at New Orleans and at special points higher up the river.

It may be pointed out that below Baton Rouge, 800 odd miles from Cairo, the appearance, physical features, and general characteristics of the river are quite different from those existing above. The slope is less, the average depth much greater, and width less. Caving is comparatively slight, and the difference between high and low water stages at New Orleans is only about one-third of that at Arkansas City.

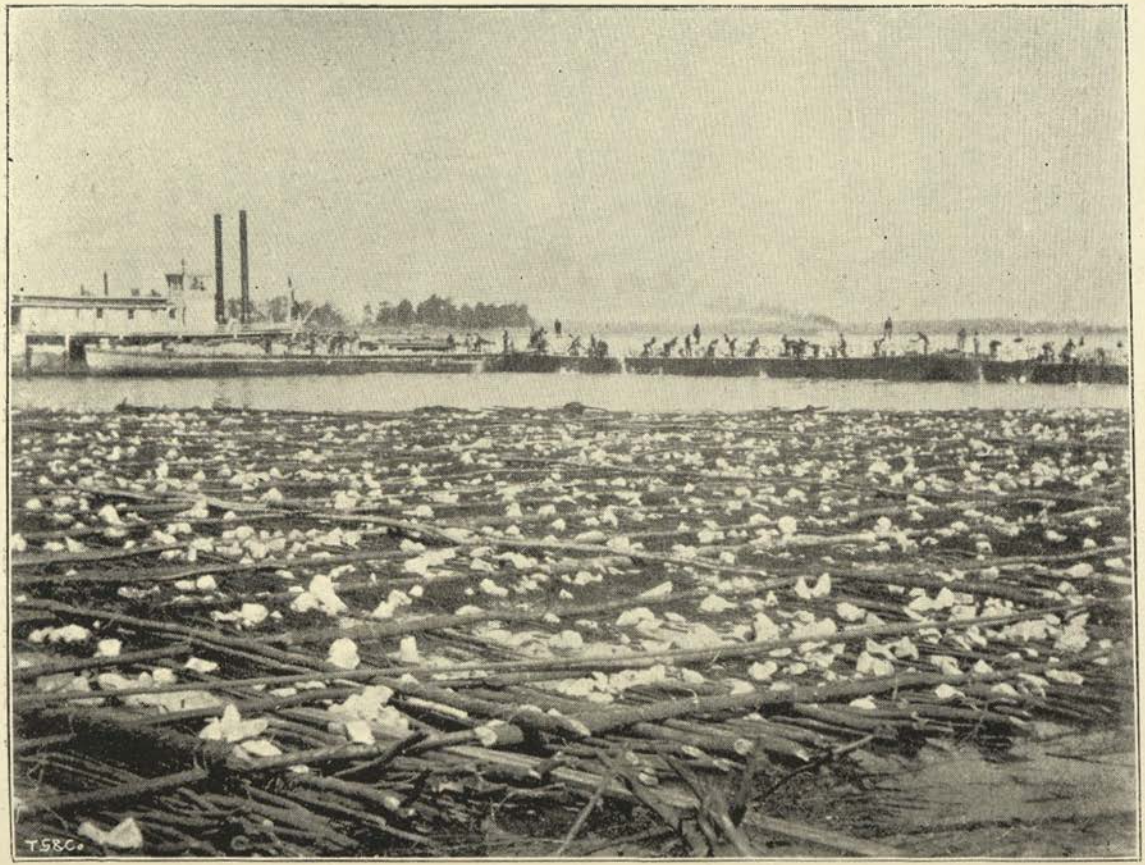
CONTINUOUS REVETMENTS.

THE first work mentioned was built in 1878 at Delta Point opposite Vicksburg. It consisted of revetment of the bank merely below low water, it being expected that the upper bank would not need protection. The revetment was made of willow mattresses 150 feet long by 50 feet wide, constructed on floating ways which, after being launched and floated into position, were weighted with stone and sunk to the bottom.

The floating ways or barge on which the mattress was manufactured consisted of two coal boats, each 165 feet long, placed parallel to each other and bolted together. On them the ways proper were erected, having inclined skids 6 feet apart running across the barge, supported by posts. The runs extended 6 feet beyond the edge of the barge; the timbers of the framework were 4 × 6 inches. Stringers were fastened below the runs at the lower end to strengthen them. On this barge the mattress 50 × 175 feet could be constructed. When ready to manufacture the mat, material barges were towed alongside of the mattress ways and the material taken from them as needed.

The mattress construction consisted in first placing longitudinal stringers made of poles 6 inches in diameter at the larger end, fastened together with wire and spikes 8 feet apart on the runs; each stringer stretching along the barge the full length of the mattress. Across the stringers and on top of them were then placed transverse stringers also 8 feet apart, fastened to the longitudinal system at the intersections. At the intersections pins of hickory 1 inch in diameter and 3 feet long were also inserted in a vertical position.

On the top of this framework between the pins were then laid layers of willow brush, each layer at right angles to the one below, until a thickness of 2 feet was obtained. On this brush was placed a set of transverse stringers 8 feet apart in the same manner and of dimensions as those below. The pins were let into these stringers and secured by wedges and nails thus connecting the upper and lower system of poles. Wire was also used to further strengthen the connection between the two frames.

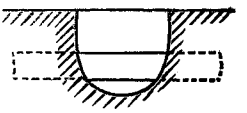


Type of Mattress used in lower reaches of the River.

When the mattress was completed, ropes were fastened to it in such a manner as to be readily freed by toggles when on the bottom. Then it was launched from the ways into the water and towed to the part of the bank to be revetted. When in position sufficient rock was thrown from the mooring barge and flats to cause it to settle to the bottom.

The first mattresses extended from the low water contour down to 150 feet on the subaqueous slope. One could be made and sunk in a day. In some instances the depth of water at the outer or lower edge of the mat was as much as 80 feet.

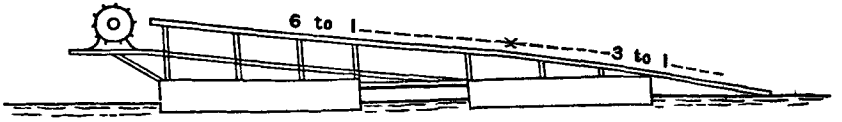
In 1880 it became apparent that the protection of the subaqueous bank only, leaving the upper slope exposed to the destructive action of the currents, was bad practice, and that some method would have to be adopted for the preservation of the latter. The bank was therefore graded to a slope of about 45 degrees; and on this was laid a mattress of about 8 inches in thickness, the mat being kept from sliding by wires fastened to dead men on the bank above. A "dead man" is a beam buried horizontally in the ground forming an anchor.



In 1881 the method of mat construction was entirely changed. Pole frames and pins were abolished, wire netting was substituted for the frames and held together by stitches made through the mat.

Change in method of construction in 1881.

The mattress boat used at this time consisted of two barges 20 feet wide, 150 feet long and 3 feet deep (*see* sketch cross section),



with a raking end allowing an overlap on the shore for connecting the mat to the revetment above water.

"The barges were rigidly fastened to each other by beams 8 inches by 18 inches in section and 30 feet long, a 9 feet space being left between. This space was spanned by 4 × 6 inch sills at intervals of $5\frac{1}{2}$ feet which supported the posts, 4 × 6 inches and $6\frac{1}{2}$ feet apart, on which the runs rested. The runs were of cypress, 4 × 6 inches beveled on the upper side and $5\frac{1}{2}$ feet between centers. The top of the runs on the high side was about 13 feet above water level. There was a break

in the run slope as shown in the sketch. A floor 4 feet below the top of the runs enabled the men to work under the mat and also acted as a brace to the posts. A platform 8 feet wide projecting from the high side of the ways extended the whole length of the barges." On this platform was a drum of about 3½ feet in diameter on which the wire netting was manufactured. The detail of the drum and manufacture of the netting need not be described as this system of mattress-making was very shortly given up.

In constructing the mattress, longitudinal poles were first laid 8 feet apart, not for the purpose of strengthening the mat, but to assist in launching it. On these poles was placed the wire netting. Over the netting came the brush in three layers to the thickness of 1 foot. Then the willows were sewed to the wire netting with No. 12 wire, the seams being 4 feet apart and in lines parallel with the length of the mat.

Cross rows of poles were wired to the top of these mats to keep the rock ballast from rolling off. The operation of sinking was similar to that previously employed.

Early decisions of the Mississippi River Commission.

The Commission, having made a study of the problem, formulated in 1881 a project for the improvement of the river, which provided for contraction works and bank revetments. The bank revetments were intended to stop erosion and caving of concave bends. Quoting from their report of 1881: The process of laying this revetment will vary greatly in different localities, but will commonly, or at least in many cases, consist in first freeing the bank of snags, stumps and brush, and then placing a mattress . . . upon that portion of the slope extending from deep water to a few feet above the water level, and weighting it with sufficient rip-rap stone to hold it in place; the revetment to be afterwards completed by grading the bank above the water-level to a proper slope with streams of water under high pressure, after the manner commonly followed in hydraulic mining and laying thereon a supplementary mattress, overlapping the one previously laid and extending up to the crest of the bank. . . . Whenever it may be deemed safe to omit the mattress on the upper part of the slope, and place the stone covering directly on the bank, that course will be pursued.

The two reaches first selected for improvement were a length of 40 miles at Plumb Point above Memphis, and a length of 35 miles at Lake Providence below Greenville. Radical changes were made in

the general design of protection works. Harbour mattresses were not considered efficient for permanent protection because of their small size and detached condition.

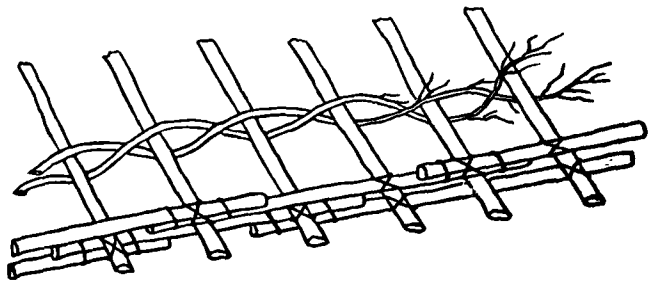
The first change then was to increase their width to three times that formerly used, to build and sink them in continuous stretches of from 500 to 2,000 feet, and to prepare the bank by removal of snags with boats specially built for that purpose. The first mattresses used by the Commission were of much the same description as those made in 1881, but constructed on a specially designed machine barge which, however, was not very successful.

The Woven Mattress.

In 1882 the revetment of Delta Point was vigorously proceeded with, but on a different plan, the "woven" mattress being adopted.

The method of construction was as follows: A moving barge 170 feet long by 26 feet wide was placed end-on to the bank at the upper end of the slope to be revetted. The barge was held in position by Manila lines leading to dead men on the bank and to anchors in the stream above. On the down stream side of this and secured to it by 1-in. lines were the ways, placed with their lower ends of the runs up-stream.

"The construction of the mattresses was commenced by laying 30 ft. willow poles across the runs and near their lower ends. These poles were lapped from 4 to 6 ft. and fastened together with No. 12 wire and four or more 6-inch boat spikes. Longitudinally between the runs, about 6 ft. apart, were placed willow poles of the same dimensions, with their large ends resting on the transverse system and tightly wired and spiked to it as shown in the marginal sketch.



On the larger ends of these longitudinal weaving poles a third set similar to the first was laid transversely, and all three firmly spiked and wired together, thus forming a mat head or cross selvedge for the woven mat which kept it from unravelling and acted as a strong fastening in sinking, etc.

"Before commencing to weave the mattress this upper frame or head was fastened to the mooring barge by 1-inch lines. Willow brush was then woven over and under the longitudinal poles, the brush being about 30 feet long and

3 inches thick at the butt. The weaving was accomplished by placing the brush over one pole and under the next, over the next, and so on until its end was reached, when it was forced down the runs and poles until the transverse poles or head was reached, to which it was made to fit tightly by means of mauls. This operation was carried on all along the ways by different gangs of men and repeated until the 30 feet of poles or one shift was nearly filled with woven brush, only space enough being left on which to spike and wire other poles, thus making a continuous wooden thread on which to continue the weaving. Every 100 feet transverse poles similar to those at the head were placed across the mat to give it strength and longitudinal poles 12 feet apart were bound to it on top, forming cribs to keep the rock from falling off when sunk on a steep sub-aqueous slope.

"When one shift was woven it covered the entire ways and in order to continue the weaving it was necessary to remove this. To do so the lines holding the ways to the mooring barge were slackened and the ways moved down stream from under the mats, the movement being produced by the force of the current. They were moved just the length of a weaving pole for each shift until the end of the mattress was reached, when a strong frame selvedge similar to the head was constructed, and the last shift launched into the river. The floating mattress was held at the upper end by lines to the shore and to the mooring barge and on shore side by lines leading to dead men or trees.

"These mattresses were about 400 ft. long by 144 ft. wide, the method of sinking being very similar to that employed for the earlier designs.

"After each mattress was sunk, sharpened piles 40 ft. long and 15 in. in diameter were driven through the shore side to keep it from sliding out into deep water where the slope was abrupt.

"After the subaqueous slope had been covered in this manner, the upper bank was graded with shovels, but this proving very slow and expensive, sluice grading was attempted with fair success.

"After grading the bank continuous lines of poles 30 ft. long by 5 in. in diameter, well wired and spiked together, were laid on it parallel with the top, the rows being 10 to 12 ft. apart. On these transverse poles were spiked and wired together in the same manner in rows reaching from the top to the bottom of the slope, and wired at intersections with the others. Upon this frame willows 20 to 30 ft. long and 2 to 3-in. at the large end were laid with the butts up hill, the bushy or leafy part of the top being covered by the butts of those below. On the brush were placed lines of longitudinal poles directly over those in the bottom frame and fastened to them by No. 8 wire."

If the upper revetment did not overlap the mattress, a connecting mat was built to make the protection continuous from top of the bank to the river bed. Over the upper bank revetment sufficient rock was placed just to cover the brush. Including towing, grading and other expenses the cost per lineal foot of the revetment was about $14·00.

In 1883 work proceeded without much change of construction. Electric lights were introduced for night work. An entire floating plant specially designed for revetment construction was employed. Wire shore fastenings were substituted for Manila ropes. Iron rods with welded eyes at each end were placed alongside the weaving pole, the ends being connected by lap rings, and at certain localities twisted wire cables were placed longitudinally and secured at intervals to the weaving poles. Hydraulic grading cost about 3 cts. per cubic yard of material removed.

At one place a detachable mattress head was tried instead of a mooring barge. It consisted of a braced frame of wood to which the mattress was fastened by lines which were released after sinking by a lever and trips.

Though one mattress 152 feet wide and 1,200 feet long was sunk with this head, it was not generally adopted, the old method of mooring barges being preferred.

In 1884 the mattresses were made stronger by weaving around only two poles and securing the tails by binding poles wired down to the weavers, and also by introducing half-inch iron rods and wire ropes, both longitudinally and transversely. On the upper banks wire ropes were also used and more stone, while the subaqueous mattress was prevented from sliding up the bank on a rising stage by a row of piles driven about 5 feet below the low water contour

By 1885 experience had demonstrated the necessity for strengthening the revetment to fit it to withstand the continuous force of the current and prevent sloughing of the bank. The mattresses were strengthened all through, wire and Manila ropes being used freely with this object, and several devices were tried to prevent sloughing of the upper bank. Mention is made of one place where a trench, 90 feet long, 4 feet wide at bottom and 16 feet deep, was excavated and refilled 6 feet with rock, with great benefit.

In 1887 the cost of bank revetment had reached $25 per running foot

In 1888 the mattress work at Plumb Point was 200 feet wide, upper banks were graded to a more gentle slope, brush was omitted from the upper bank, and in its place stone pitching or paving was laid on the bare ground to a thickness of 10 inches In this year, 1888, 4,000 feet length of continuous revetment was placed in Hopefield

Bend of total width of 335 feet, the subaqueous mat being 196 feet wide, and the upper bank revetment on a 3 to 1 slope being 139 feet wide.

In 1889 steel cables were used for the first time with shackles or toggles as headlines in place of Manila ropes. The latter required constant adjusting to maintain an equal pressure, whereas the steel cable can be placed at once and the strain distributed between the headlines without difficulty. Cast-iron cavels on the mooring barges were substituted for wooden. Bank slopes were flattened as the simple remedy against sloughing, and in some cases 8 or 10 feet of the crest of the bank was left vertical, as it was found little caving occurred there if the lower part was protected.

Omission of mattress above water level.

About this time it was found that when the upper bank had been previously revetted with willow and brush ballasted, the willows above low water line rotted out after a few years, and it was therefore decided to dispense with the willow work altogether on the upper bank and generally to protect it merely with stone carefully laid on the sloped bank. When the willows are constantly submerged this deterioration does not occur, the only damage they are exposed to being that due to running water.

Before proceeding further with the history of the development made in bank revetment reference may be made to the Mississippi Commission's report for 1891, which gives as an appendix a paper by Mr. A. G. Nolty, describing in detail the approved methods followed in the construction of standard bank protection in 1890. It shows well the stage reached at this date, and is a full description of the method of manufacture of woven mattresses; and though such are not now being used on the Lower Mississippi, "fascine" mattresses being considered preferable, they are still approved and used by some of the engineers of the higher river. Quotations from this description with interpolations by Mr. Coppee will therefore be given.

Standard Continuous Revetment, 1890.

After grading and clearing of snags, an abutment of 6 piles braced together is constructed on the low water line against which the inside edge of the mooring barges are to rest. Below this abutment and along the zero line single piles are driven 100 feet apart to keep the mattress

Collection of Materials for Bank Revetment.

while under construction over the zero line during fluctuation of the stage; the tops of these piles are cut off after sinking the mattress.

"While the abutment is being constructed, two mooring barges lashed end to end are placed alongside of the bank above the abutment. Outside of these barges, parallel with them and with the ways touching the gunwale, is placed the mattress or weaving barge."

The headlines connecting the mooring barges with "dead men" on the bank consist of wire cables, the up-stream one 1¼ in. in diameter, the next two 1⅛ in. and last three 1 in. in diameter. (*See* sketch opposite copied from Mr. Coppee.) These cables have an eye spliced in one end for fastening them to the cavel of the barge. On the upstream edge of the latter the timber heads have iron bands forming eyes through which the eye of the cable is fastened by a 1¼ in. iron bolt.

While the mooring lines are being run the head of the mattress is under construction.

"Hardwood poles as large as can be conveniently handled are laid in two lines on the ways over and parallel to the inner gunwale. These poles lap each other 10 to 15 ft., the two lines breaking joint. Where they lap they are spiked together with 8¼ in. spikes every 2 ft. and also tied together with No. 12 galvanized wire at intervals of 10 ft. except at the laps where two ties are made. This line of poles is equal in length to the width of the mattress."

Upon these poles, at intervals of about 7½ ft. and at right angles to them, the butt ends of the weaving poles are securely fastened with two spikes and a lashing of wire. Upon these latter another set of poles similar and parallel to the first are placed, spiked and wired, and the whole head thus formed securely fastened with wire.

"The weaving poles are live willow or cottonwood brush, reasonably straight, 4 to 6 in. in diameter at the butt and from 25 to 30 ft. long.

"To facilitate weaving, all knots are trimmed off. A cable made of 8 strands of No. 12 wire is fastened around the head of the mat at every third weaving pole and run alongside of it, being fastened thereto by two staples. These cables are 24 ft. long with an eye in one end, to which after each shift of the mat, a new length is looped in weaving. Ten continuous cables are thus formed in the mat, greatly strengthening it longitudinally."

While the head is being formed the mattress headlines are being run out, and when it is finished, they are fastened to it. These lines are five in number, varying from 1⅛ in. in diameter to ¾ inch. They lead from shore fastenings as in the case of the mooring lines and pass under the mooring barges, being fastened to the mat head loop by a pin shackle. The mat head loop is made of 2 in. Manila rope fastened to the head and running back into the mat about 25 ft.

"The brush used for weaving is live willow of any length above 25 ft. and from 2 in. to 4 in. at the butt.

"A full complement of men for a 200 ft. wide mat is 54, under a foreman divided into three equal gangs. Each gang consists of five men on brush barge, twelve men in weaving party and one man on mat mauling brush tightly into place as the weavers push it down. Each gang builds one-third the width of the mat.

"The brush barge is placed outside (below) the mattress barge about midway between the two ends, and a barge loaded with poles is hung to each of said ends.

"A coil of 2-in. rope is placed on each end of the mat barge and the free end fastened to a timberhead on the mooring barge. The skids on the ways are well slushed with axle grease or tallow to reduce the friction in weaving and launching. In a 200 ft. wide mat 27 weaving poles are used. In weaving they are close to the skids and at the upper end rest in brackets bolted to the upright posts on the mattress barge.

"The brush is passed from the brush barges to the weavers who work in pairs, and is woven by them into the mattress. The butts are placed over one weaving pole and 2 ft. beyond, being woven at the other end over the next pole, under the third, over the fourth, and so on, the light ends being always left on top."

A strip 5 ft. in width is thus woven. In the next 5 ft. the butt is reversed, the butts changing direction every 5 ft. When the mattress is woven to within 2 ft. of the end of the poles, giving about 22 ft. length of mattress, it is swung into position with the accompanying barges.

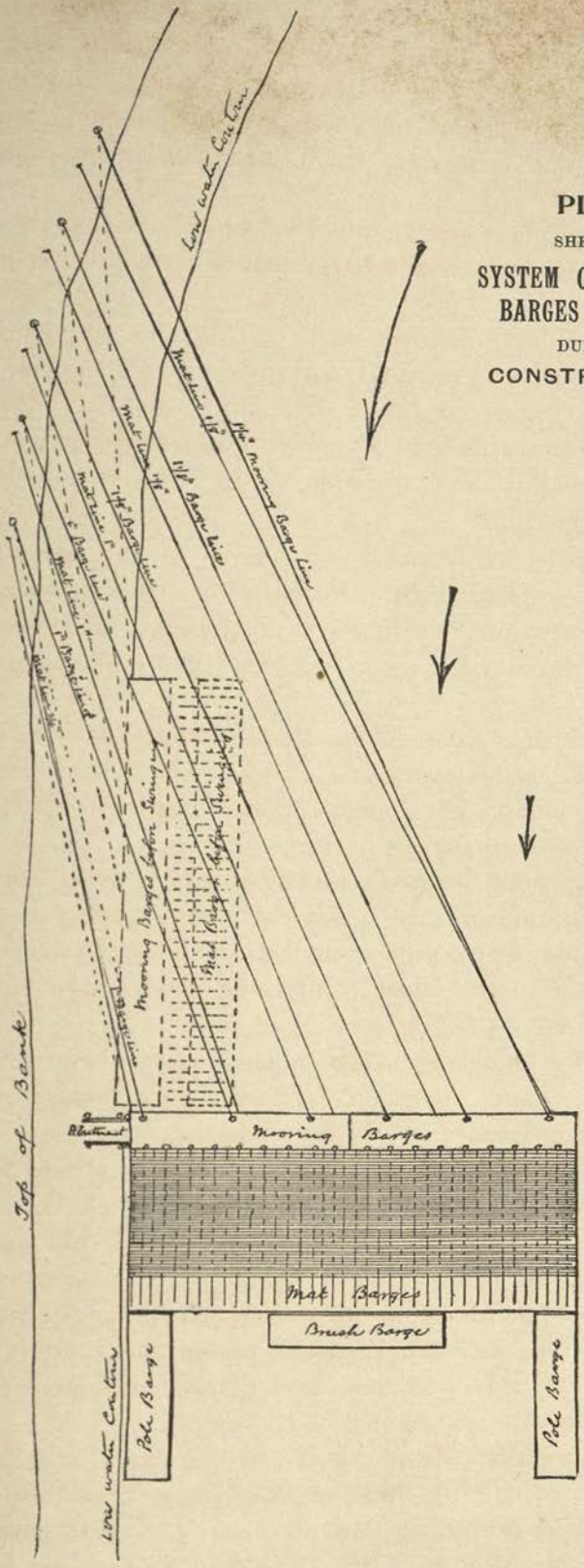
The entire floating plant is swung on two lines ; a 2-in. Manila rope on the outside and an $1\frac{1}{2}$ in. rope on the inside of the mooring barges. The headlines on the barges and mattress are slackened until the barges take up their proper position normal to the shore with their inside edge butting on the pile abutment.

"The slack in the mooring barge cables is now taken in from the bank and the strain equalized. They are then fastened permanently with clamps, the mattress headlines being treated in the same manner."

To prevent the mattress sliding too far when launching, Manila lines are fastened equidistant on the mat and pass underneath it to cavels on the ways.

"The slip lines are $1\frac{1}{4}$ in. Manila rope about 125 ft. long, there being 18 to a 200 ft. mat. Each has an eye large enough to pass over a timber head. This eye is placed over one of a line of timber heads on down stream edge of mooring barge, the free end being passed under the head of the mat and up again on its down stream side, and then hauled taut and fastened on the timber head. The mattress head is thus hung in 18 slings....."

" When one entire shift (about 22 ft.) is launched, a new set of weaving poles is spliced to the projecting ends of the first set, the butts of this set being spliced to the tops of the preceding one after having been pushed into the mat about 3 ft., thus making a lap of 4 ft. Two 8-in. spikes and two wire lashings


Low water Contour
Mooring Barges Line
Mooring Barges Line
Mooring Barges Line

are used to fasten each splice. This is continued as described to within 2 ft. of top of the second set of poles, when another launch is made, and so on."

"As soon as three shifts of mats are launched, the construction of a top grillage or framework is begun, consisting of a line of poles laid over the weaving poles and parallel thereto, lapping each other, butts to tops from 6 to 8 ft. and wired to the weaving poles every 4 ft. by lashings 2 ft. long, made of two strands of No. 10 wire ; transverse poles 8 ft. apart for the first 100 ft., and thereafter 16 ft. apart, are placed in similar manner and fastened to the longitudinal ones at the intersections by 2 ft. lashings made of four strands of No. 12 wire. This grillage is for the purpose of forming cribs to retain the stone on steep slopes. It also strengthens the mattress. ....."

"The construction of the shore mat which is expected to progress with the river mat is carried on by a gang of from 30 to 40 men. The space to be spanned in building the shore mat varies with the stage of water from 0 to 60 ft. In its construction a small flat boat is generally used from which to work. Hardwood poles of the size of the weaving poles are lashed to the river mattress with three No. 12 wire lashings 2 ft. long, and spiked with two 8-in. spikes. Willow poles are spliced to these until they reach up the slope about 40 ft. Alongside and fastened to each of the hardwood poles (the first set of transverse poles along the inner edge of the mattress) is a cable made of 8 strands of No. 10 wire, one end of which is fastened to two of the adjacent weaving poles and the other to the willow poles extended on the slope. Upon the transverse poles are laid longitudinally willow or cottonwood poles 8 ft. apart beginning with the first set about 4 ft. from the edge of the mat. The latter poles are wired to the former at their intersections with lashings of No. 12 wire 2 ft. long. The longitudinal poles are carried on lines 8 ft. apart, up to the top of the slope, and on the lower side 8 ft. apart are driven stakes 2½ ft. above the ground, to the top of which is fastened loosely a lashing of wire whose bight has been first passed under the pole. These stakes are used down to the pole nearest the water edge. Upon this framework is laid willow brush diagonally with the butts toward the top of the slopes and breaking joint throughout, except at the top of the slope. A second layer of brush is laid upon the first in the opposite direction, butts pointing to top of slope and breaking joint, the direction of each layer making a right angle with the other. On top of these layers of brush a second pole framework fastened in the same manner as the first is placed and fastened down firmly by the lashings tied to the stakes. As fast as the river and shore work is finished, transverse cables made of 8 strands of No. 10 wire and 60 ft. long with an eye in each end are run across the entire width of the mat every 16 ft., carried to the top of the bank, hauled taut and fastened to trees, stumps or dead men. They are also fastened to the mat every 16 ft. with wire lashings."

When 400 or 500 ft. of river mattress is made, longitudinal cables are run out from the mooring barge, one ⅝ in. cable close to the outer edge of the mat, another about 30 ft. inside of the first, the third ½ in. in diameter and 37 ft.

from the second, a fourth of the same dimensions 38 ft. inside of the third, and the fifth and last $\frac{3}{8}$ in. in diameter and 42 ft. from the fourth, or 45 ft. from the inner edge of the mattress. All are fastened to the mattress every 16 ft. perfectly taut throughout the mat, and secured to its head and foot when finished.

The cables are mounted on reels, the outside, or $\frac{5}{8}$ in. one, being placed in position first.

"The whole cable is reeled off, but the inner end kept on the mooring barge where the reel is set up. After being run down towards and close to the weaving barge, the spare cable is coiled down and tied for further extension. Just above the coil the cable is fastened to the mat with a wire lashing and a specially designed clamp. A tackle is then fastened to the free end and the cable hauled taut by ten men on the mooring barge. It is then fastened to the mat every 16 ft. with a clamp and lashing. The second $\frac{5}{8}$ in. cable is next run out and fastened, then follow the $\frac{1}{2}$ in. and $\frac{3}{8}$ in. cables in turn. As weaving progresses, the cables are extended until the mat is finished, when the ends are securely fastened around the foot of the mat. After the cables are run, hauled taut and fastened to the head of the mat, all additional hauling is done from the lower end of the mat."

The mat is generally completed before being loaded, but when over 600 ft. in length ballasting may begin when that length has been woven. Ballasting is accomplished by placing a loaded barge outside of the mat, then cottonwood planks, 24 ft. long, are laid from the barge to the mat and continued across it. From 2 to 4 of these runs are used, and 10 to 15 men employed on each. These men wheel out the stone in barrows and dump it along the transverse poles, loading the entire floating mat until only the poles are above water: being careful to load the 50 ft. next to the bank heavier than the rest. When the length of the barge is ballasted across the mat, the barge is dropped one length and the planks changed to the new position. The shore work is not ballasted until the river mat is sunk, except where stone is piled on the bank, in which case the shore work as well as part of the river mat can be ballasted from the bank.

"As soon as the mattress is completed and ballasted, a loaded stone barge is brought up to the mooring barge; a line is run from its head to the shore capstan of the mooring barge and another from its lower end to the outer capstan. A man is stationed at each slip line who obeys only the word of the general foreman. Stone is thrown on the head of the mattress, and as soon as the strain on the slip lines is considerable, they are carefully slacked for a short distance. The men at the inshore capstan begin to haul the head of the stone barge gradually over the submerged mat. The lower end is also gradually hauled up, the object being to bring the stone barge squarely across the mat; stone being continually thrown over on the mat and the barge hauled over until this is accomplished. The line from the down stream end of the barge is then quickly shifted to another capstan as the barge proceeds in shore."

In the meantime another stone barge is placed end on the one nearest the shore and lashed to it, forming a line of barges just below the mooring barges,

parallel to them and floating over the head of the mat which is about 10 ft. below the surface, but kept from sinking further by the slip lines.

"In the meantime one coil of 2-in. rope has been placed on the inner end of the first and one on the outer end of the second barge, and the end of each fastened to a timber head. A long 1-in. line also runs from the inner end of the first barge ashore, where a gang of men will be ready to haul the in shore end of the barge down stream should the water near the shore be without current. A steam tow boat now makes fast with one line to the outer end of the outside barge. A man is at each slip line. A line of men is distributed along each edge of the stone barges. The men on shore have hold of the 1-in. hauling line, the steamboat hanging from and close to the outer edge of the stone barges, and lying with the current. The general foreman is on the mooring barges watching the slip line men, and everything is in readiness for the final operation.

"The general foreman now gives the word to throw the stone, and as soon as the slip lines show the required strain, he orders the linesmen on the stone barges to slacken away. He then gives the word, and the slip lines are let go simultaneously. The mat settles quickly at the head, and as the stone barges are dropped down squarely over the body of the mat, the stone being rapidly thrown on to it, it also gradually settles to the bottom. When the required amount of stone is unloaded on the mattress, and it is securely on the bottom, the mattress headlines are taken up by a sailor gang by hauling on the pin lines that are loosely fastened on the mooring barges. These lines pull the pins out of the shackles and set the cables free from the mat. The mooring barges are then allowed to swing to the bank, and all cables are reeled up on their drums, being first washed and oiled."

On a bank which is caving so rapidly that the grading cannot be accomplished before the mattress is built, a foot mattress is constructed joining the main mattress with the bank ; the upper bank work being deferred until the main mattress is sunk.

"The abutment and main mattress are constructed as described, except that the hardwood poles along the inner edge are omitted, and only the regular top grillage is laid. After the mattress is sunk the bank is graded and the shore work laid down to the water edge. A connection or foot mat is then made to connect the shore work with the submerged river mat as follows :—

"The weaving barge is brought up alongside and parallel to the bank, with its upstream end over the head of the mat, and a mattress built like the river mattress except that it has a lighter head and no mooring barges are used. Instead of the heavy wire cable, wire strand is run from the head up to the top of the bank and fastened there. $\frac{5}{8}$ inch cables are used for every 200 ft. of mattress. Two or three cables are also run from the upstream edge of mat to shore to prevent the current from taking it down stream. The head of the mat when launched off will lap 4 or 5 ft. over the shore work. To launch a shift the barge is sparred away from the bank. When completed and sunk the foot mat laps over the river mat also 5 ft."

Grading.

In the earlier days grading of the slopes of the bank was done with shovels, then sluice grading was tried, but this soon developed into hydraulic grading with specially designed graders.

Sluice Grading.—A trench was excavated down the slope to the proper grade, then a wooden trough was placed in it, and the material excavated was thrown into the trough and washed down by a stream of water supplied through a hose from a water-jet pile driver moored alongside.

Hydraulic Graders.—These graders, consisting of a pumping plant carried on a suitable barge, were specially designed with powerful pumps, capable of discharging as much as 2,000 gallons per minute under a pressure of 160 lbs. with steam pressure of 80 lbs. per square inch. The water is delivered through 4-in. hoses to nozzles which, at starting, are directed against the face of a previously made graded cut, and wash down the bank as the nozzles are moved forward.

The cost of work done with hydraulic graders is quoted at from 3 to 4 cents per cubic yard, and the quantity of material moved by one grader at from 1,000 to 1,500 cubic yards per day.

Bank Revetment, 1893.

Surveys made in this and the previous year showed a deepening and deterioration at the outer or lower edge of the mattress. In some cases the mat adjusted itself. In others the test was too severe and faults occurred. The Commission therefore decided to further strengthen the mattress to make the outer edge more flexible, &c., resulting in the adoption of the "fascine" mattress, after experiments had been made in the construction of two types. One had fascines placed normal to the bank, and the other the fascines parallel to it. The former type was finally adopted and is now in general use on the Lower Mississippi.

The annexed plates of photographs of a mat in process of construction, taken during an inspection by the writer in December last, illustrate well the difficulty of situation and magnitude of the protection works undertaken so successfully by the Mississippi Engineers.

Fascine Mattress Revetment.

The following description written by Captain Roessler, U. S. Corps of Engineers, the officer in charge of the first and second districts at that time (*see* Chief of Engineer's report, 1894), gives clearly the methods of construction then followed and still generally adhered to at the present time.

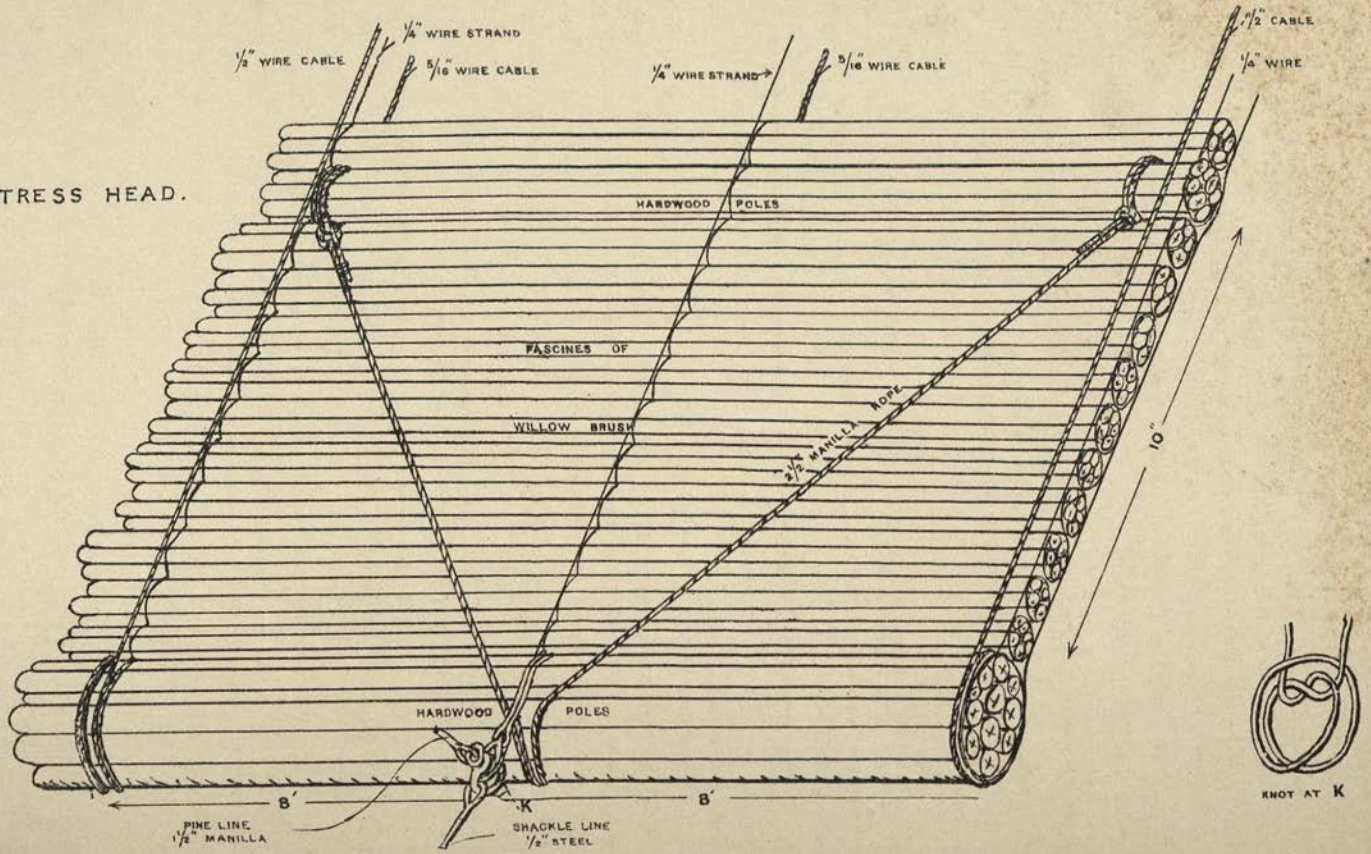
Caving Bank, Caruthersville, Mo. Mat plant in distance. Dec. 1898.

Nearer View of same Plant, looking Downstream.

Mat Plant. Constructing Mat for Caruthersville, Mo. Dikes. Dec. 1898.

Caving Bank near Caruthersville, Mo. Mat Plant and part of Mat for foundation of Dike. Dec. 1898.

MATTRESS HEAD.



Plan No. XII.

"The plant required consisted of one set of mooring barges, one set of barges with inclined ways and one set of fascine barges.

"The barges of each set, when placed end to end, had a length equal to or greater than the width of the mattress to be constructed The mooring barges were of the same construction heretofore used with the woven type of mattress, and were moored across the current in the same way. The mattress barges were also the same as heretofore used with the following additions: Underneath the platform were placed a number of cable drums, one under each inclined way or skid, on which was wound and from which was payed out, as the construction of the mattress progressed, the steel wire strand which constituted the longitudinal strength of the mattress, and to which the fascines were attached or woven by the method to be hereafter described. The distance between the drums was 8 or 9 ft. according to the particular barge used. At the highest point of each way an iron sheave was placed, over which was passed the strand from the corresponding drum. The drums were all provided with friction brakes by which a uniform tension was kept on the strands while the mat was in process of construction. The fascine barges were ordinary square end decked barges, on which were erected temporary platforms the same level as the platforms of the mattress ways. These barges were put end to end and lashed parallel to and close up to the down stream side of the mat ways. On the side of the platform nearest the mat ways were erected the 'formers' in which the brush was laid, compressed, and bound into fascines.

"*Construction of Mattress.*—The mooring barges being properly moored in position across the current, the mattress ways, to which had been lashed the fascine barges, were brought in position on the down stream side and secured to the mooring barges by three lines, one at the centre and one at each end. The first step was to construct the mat head. This consists of a bundle of poles $2\frac{1}{2}$ to 3 ft. in diameter, well bound together by wire strand so as to form a beam of great strength, of some rigidity and having also considerable flexibility. The poles were of hardwood 5 to 8 in. in diameter at the butt, and laid so as to break joint with each other. The beam is as long as the mat is wide and forms the connecting link between the mooring cables and the mattress. It was moored to the bank by steel wire cables independent of the moorings of the mooring barges. The number of cables used depended on the width of the mat and strength of the current. Eight cables have been used for a mat 300 ft. wide. They are spaced at unequal intervals, being closest together near the out-stream end where the current is strongest, and farthest apart towards the shore where the current is more moderate. At each point where the cable is to be attached a heavy Manila rope doubled is wound round the mat head as indicated in the sketch annexed."

"Its (the cable's) free ends are passed over the mat and attached to a second and smaller mat head constructed in the mattress 10 ft. from the head of the mattress. The other end of the rope is connected by an ordinary shackle to one end of its mooring cable, the other end of the cable being then passed underneath

the mooring barges to its anchorage on the bank. The wire strands from drums on the mattress ways are passed over their proper sheaves and wound around and secured to the mat head. The weaving strands, which are ¼ in. steel strand and for convenience cut into lengths of about 50 ft., are also attached to the mat head, one for each of the longitudinal strands upon which the fascines are woven.

"For the construction of the fascines and the mattress the labour is divided into three gangs, one to hand the brush down from the barges, the second to carry the brush to the formers and to construct the fascines, the third to weave the fascines into the mat.

"The second party receiving the brush from the first party carries it to and distributes it in the 'formers.' The brush is put in two layers, one with the tops in one direction, and the other with the tops in the opposite direction, care being taken to break joints as far as possible and especially to prevent two butts from overlapping. Enough brush is put in to make a fascine 10 to 12 in. in diameter. It is then choked every 8 ft. and bound into a fascine by No. 12 steel wire. The chokers consists of iron chains of suitable length and strength, having one end secured to one side of the former. Each chain is brought over the brush and a lever inserted through a ring in the free end and borne down upon by the weight of one or two men, compressing the fascine while it is being wound with wire. The third party assisted by the second party raise the fascine out of the formers, slide it along the skids which connect the former with the top of the mattress ways, and down the latter to its position in the mattress next to the mat head. The weaving strand is then passed over the fascine down underneath it, and up between the fascine and mat head, crossing at the same time the bottom longitudinal strand. It is then put into a 'haven clamp' and drawn as taut as four to six men can do it with double block and tackle. The strand is temporarily stapled to a pole of the mat head. The second fascine being in place, the weaving strand is passed over the first and second fascine down underneath the second, and up between the first and second, at the same time crossing the bottom longitudinal strand as before. It is again attached to the clamp and drawn taut as before by block and tackle and temporarily stapled to a piece of brush in the first fascine. When the strain is first put on the strand, a tap on the pole of the mat head to which it has been temporarily stapled is sufficient to dislodge the staple and allow the strand to completely encircle the first fascine. Details of the method of weaving are shown on the sketch. When the ways have been filled, the mattress is launched in the usual manner and the construction continued. The tenth fascine is made of hardwood brush or poles, and to it are attached the free ends of the large Manila ropes which are wound around the mat head. The weaving and bottom strands are clamped together by a cable clamp every 10 ft., and at points intermediate between the clamps both strands are stapled to the brush to prevent the fascines from separating in the process of weaving.

"On top of the mattress thus constructed are placed rows of poles 16 ft. apart extending up and down stream. They are lashed to the fascines by No. 7 silicon bronze wire every 5 ft. and at intermediate points by strong steel wire lashings. The object of the rows of poles is twofold ; first, they prevent the stone from slipping off the mat when it is sunk on a steep slope ; and second, by being lashed to the body of the mattress by non-corrosive wire they prevent the deplacement of the brush after the steel wire weaving strand and other corrosive connections shall have rusted away.

"At the out stream edge of the mats the poles are cribbed up two-deep to better insure against the tipping of the stone when the mat is sunk or when it is subsequently undermined by scour at its edge.

"With a mattress of this type 300 ft. wide the maximum amount built in a day was 160 ft. with 246 days' labour. The ballasting and sinking of these mats is performed in a similar manner to that employed in the woven type. In ballasting it is necessary to do the work rapidly and sink the mattress immediately afterward. This precaution is made necessary by the great compactness of the brush fascines and the rapidity with which they accumulate sediment after they have been pressed under water by the ballast. So rapidly do they accumulate sediment that if there is any considerable delay in ballasting, portions of the mattress on which the ballast may be a little excessive may be carried below the surface of the water by the weight of the accumulated deposit before it is ready for sinking.

"Brush not exceeding 3 in. in diameter at the butt, makes a fascine of uniform strength, thickness and compactness.

"One-half and $\frac{5}{8}$ in. strands are used for the bottom longitudinal strands, the $\frac{1}{2}$ in. size being used at the channel edge of the mat where the current is greatest, and the $\frac{5}{8}$ inch nearer the shore.

"Smaller strands than these were used in a few of the mats when the supply of the larger strands fell short ; but in such cases additional longitudinal strands were stretched over the top of the mat after it was completed, and clamped at intervals of 10 ft. to the weaving strand in the same manner as the latter was clamped to the bottom longitudinal cable. The $\frac{1}{4}$ inch strand is used exclusively for weaving. Two forms of clamps have been used, the Crosby and a home-made clamp. Various forms of staples have been used. A staple of the fence-wire type, $1\frac{3}{4}$ in. by $\frac{5}{8}$ in., made of No. 9 wire, is a good, cheap and suitable form.

"The oblique position of the mattress head cables to the head of the mattress, in the form of construction just described, exerts a strong shore thrust on the mat head in the process of sinking. This thrust is taken up by the strong mat head and the mat itself, which together have the requisite rigidity to withstand the thrust without danger of doubling up."

The work done in 1893-94, including reaches over 2,000 ft. in length, consisted of a continuous mattress 250 to 300 ft. wide, an

auxiliary connecting mattress and shore paving of 4 to 6 inches of spalls overlaid by 6-inches of stone extending up the bank to about two-thirds stage. The cost varied from $26 to $30 a lineal foot of bank.

With a gang of 250 men a good day's work is said to have been from 120 to 150 feet length of mattress. The cost of the work depends on the difficulty of situation, the lead of materials, and the experience of the laborers in this description of work.

The following is a statement showing distribution of the materials used at Hopefield Bend in 1893-94 :—

River mattress, 310 ft. broad—

Brush	1·639	cords	per	100	sq.	ft.
Poles	0·053	,,	,,	,,	,,	,,
Stone	0·625	ton	,,	,,	,,	,,
Steel wire	4·861	lbs.	,,	,,	,,	,,
Copper wire	0·546	,,	,,	,,	,,	,,
Wire strand	10·965	,,	,,	,,	,,	,,
Clamps	1·5	,,	,,	,,	,,	,,

The cost was $5·94 per 100 sq. ft. of mat, or of bank covered was $6·07 per 100 sq. ft.

Connecting mattress—

Brush	2·355	cords	per	100	sq.	ft.
Poles	0·122	,,	,,	,,	,,	,,
Stone	0·66	ton	,,	,,	,,	,,

The cost was $6·987 per 100 sq. ft.

The upper bank revetment of stone cost $9·20 per 100 sq. ft.

The rate of the whole work was $31·52 per running foot of bank.

Mr. Coppee remarks : "All the recent surveys of the revetted reaches tend to prove that when the bank is protected, no matter how strong the revetment, the channel is deepened just outside of the sub-aqueous work, and under its outside edge causing it to take a steep grade. If the mattress is built with sufficient flexibility, strength and compactness, the ultimate result will be the steepening of the sub-aqueous slope without destroying the efficiency of the work." Therefore, as he points out elsewhere, "the foot of the mattress should always reach beyond the greatest depth of the inshore thalweg, if possible within specified limits of economical practice."

In 1894 nearly all mattresses constructed in the first, second and third districts were of the fascine type, which was thereafter recognized as the standard. While more expensive than the woven

type, it is claimed it can be constructed with much greater facility, and as much as from 150 to 180 feet length can be built in one day under favourable circumstances.

Advantages of the fascine type.

Mr. Nolty, Assistant Engineer, who has had great experience in this class of work, says: "The great advantages the fascine type has are: its density which prevents undermining; its flexibility which allows it to accommodate itself without rupture to the inequalities of the bottom, and to generally follow any cutting away under its outer edge with the result of finally checking this undermining; and its great strength which makes it much less liable to rupture while sinking."

One of the most extensive pieces of bank protection constructed in 1895-96 was 10,190 lineal feet of revetment on the Lake Providence reach. The mats were of the fascine type and were made on old style woven mat barges adapted for the construction of fascine mats by attaching a yoke or former to each skid. When the yokes were filled with sufficient brush to form the fascine the brush was loosely bound by wires and slid down the ways. It was then tightly bound together with sewing cables which were hauled taut by block and tackle on the mat in the usual manner. An arrangement of brakes, which operated by a foot piece through the platform on a series of levers clamped to the reels on which the wire strand was wound, kept an even tension on the under mat cables.

The upper bank revetment was reduced in thickness from 10 inches at water level to 6 inches at top. The total cost of one season's work was $163,164 on a length of 5,550 feet, giving a rate per running foot of $30·44. The mats were 300 feet wide.

The materials used on this work averaged per 100 square feet as under:

Stone	... cu. yds.	0·82	Galvanized wire No. 12	lbs.	2·40
Brush	... cords	1·41	Silicon bronze wire	... „	0·06
Poles	... „	0·05	Spikes	... „	·09
$\frac{5}{8}$ in. wire strand	... lbs.	1·39	Magnolia clips $\frac{5}{16}$	... No.	·79
$\frac{9}{16}$ in. wire strand	... „	1·74	Cable clamps $\frac{5}{16}$	... lbs	·0[illegible]
$\frac{5}{16}$ in. wire strand	... „	2·42	Staples	... „	25
$\frac{1}{4}$ in. wire strand	... „	6·09			

Expressed conclusions of the Mississippi River Commission in 1896.

In dealing with bank protection and contraction works in 1896 the Commission traced the development of bank revetment, they explained why its progress had been slow, and recorded definite opinions and conclusions on certain points of great importance in the consideration of this subject. Quotations from their report for 1896 are given below :—

"In the preceding reports of the Commission, accounts have been given in greater or less detail from year to year of the construction, cost, and subsequent history of the various works for bank protection and channel contraction in the bed of the river, which have been built under the recommendation of the Commission. One important result of experience in respect to these two kinds of channel work has been to emphasize more and more the relative importance of bank protection as compared with works for contracting the channel way by the upbuilding of new banks. It is now considered settled that in a plan for the permanent improvement of the channel by the contraction of its low water width, the work of bank protection should precede the permeable dikes and other structures of that class, and that the latter may be regarded as supplementary in function and as necessary only in a minority of cases. For several years past the amounts expended on such works have been relatively small. . . . . .

"A point has been reached now at which some important facts can be definitely stated. While it is not possible to say that the form of bank protection employed in the last works of that kind constructed is incapable of improvement, it is undoubtedly much superior to that done in the earlier history of the work, and no promise of advantage by further change appears at this time. The work done at Lake Providence Landing within the last two years . . . is an example of the work here referred to. Its distinguishing characteristic is the fascine mattress constructed of very small flexible poles and brush made up first into long bundles and then woven with a wire warp into mats 300 feet wide and as long as may be desirable up to 1,200 feet and upward. With this form of mattress, sunk and secured by the methods now employed, and sufficiently heavy upper bank rip-rap it is believed to be possible to hold any caving bank on the river, barring extraordinary accidents or mishaps. But it costs in round numbers

$30 per running foot of bank protected, which is 2½ times the cost originally estimated by the Commission.

"In situations where large interests depend upon holding a comparatively short line of bank as at city harbours, points where cut-offs are threatened, or levees of exceptional importance are liable to be breached by caving, the efficiency of bank protection at a cost not incommensurate with the interests involved is a demonstrated fact."

Then, after touching on the difficulty of procuring sufficient willows for extensive mattress revetment of the recognized standard type and mention of the applicability of submerged spur dikes to the lower reaches of the river, they stated that it gradually became recognized several years back "that it was not possible by any or all of the methods which had been employed to accomplish such permanent improvement of the river from Cairo down as was necessary to meet the urgent demands of commerce within any reasonable time to come." It was this "disagreeable but unavoidable conclusion" together with the wonderful development of the hydraulic dredge which led the Commission to undertake experiments in the dredging of the low water bars to meet the necessities of commerce. And the success of these experiments has been such that bank revetment is confined at the present time to the maintenance of previously constructed lengths, to holding banks in front of important levees, to preventing threatened cut-offs, and to the protection of harbour and city fronts.

Present Practice.

The above notes and extracts give a fairly correct idea of the methods of construction followed at the present time. There has been but little change since the adoption of the fascine type known as the standard, except in minor details of construction.

The fascine formers are now placed on the mattress barge. The stone revetment is carried up to about two-thirds stage of the river. The top of the bank above the stone revetment is left ungraded. The graded slope is protected with stone, rock up to one man size being thrown or carelessly packed on 3 to 4 inches of spawls. The slope is not "pitched" to an even surface by laying the stone in courses, as this would merely tend to prevent its settlement as the earth is washed out underneath. The bank

protection used on the Canadian canals is of a very similar character, though of greater thickness to withstand the back wave wash to which it is there exposed.

Finally, it may be again observed that the important principle involved in this method of bank protection is the prevention of scour of the sub-aqueous slope, the cutting and undermining of which is the cause of practically all caving, slipping or slumping of the upper slope or edge of the bank. The latter needs comparatively little protection against erosion during floods if the lower sub-aqueous slope is maintained and kept stable.

River View, New Orleans.

DISCONTINUOUS OR DETACHED REVETMENT.

At New Orleans the shore line is much broken up by wharves and landing stages, and where revetment was required it was not feasible to use the continuous mats; submerged dams or dikes known as submerged spur dikes were therefore adopted in the early days of the Mississippi River Commission for the protection of the banks in that neighbourhood.

Submerged Spur Dikes.

These spur dikes were placed normal to the bank at intervals of from 500 to 1,500 feet. Since the commencement of their construction in 1884-85, it has been found necessary to supplement them at various times by placing intermediate spurs, until, at the present time, considerable lengths of banks are completely carpeted with this detached construction. (*See* Chief of Engineer's reports for late years.)

The earlier spurs were built on a woven mattress foundation 200 feet wide, extending into the stream about 350 feet from the low water contour. It was first sunk by means of rock enclosed in narrow crib work, built along the edge of the mat. Then on this mattress, on a line about 75 feet from its upstream edge, were sunk six wooden cribs, the bottom one 60 feet wide and the top one 22 feet wide. The bottom one had a length of about 300 feet, while the lengths of the others were so arranged as to give the completed dike a top surface with slope of about 3 to 1.

The cribs were made of timber frames, connected with iron bolts and wooden pins and filled in with brush and rock, the rock being placed in pockets left in the brush filling for that purpose. The cost of each spur dike was about $12,000.

In 1887 spur dikes, 500 feet apart, were used to protect the city fronts of Memphis and Greenville, Mr. Coppee being in charge of the latter.

The cost of ten dikes at Greenville, including the upper bank revetment, at each, was $101,000. They protected about 5,000 feet length of bank, giving a cost of about $20 per foot protected.

At New Orleans the cribs were thickened to 6 feet and the rock

pockets reduced to one-third the thickness, the cribs being loaded to as much as the lowering lines would stand before being sunk.

In the next year, 1888, it was found that the Greenville dikes required supplementing, and several hundred feet length of continuous revetment was laid between the dikes.

At New Orleans the dikes built in 1884 were found in good condition. An extension of the work built in this year required at one point the sinking of the mat in 150 feet of water. The cribs were 450 feet long and the mattresses still longer. The ways not being of sufficient length, a supplementary mattress was built of the old pin and frame style and sunk outside the other. It was placed in 153 feet of water, 300 feet from the shore, in a current of 5 feet per second; being sunk in the usual manner with the assistance of an extra lowering barge and extra guide chains from anchors. Its cost was $9·56 per 100 sq. feet, and that of the woven river mats $6·39 per 100 sq. ft. The crib work cost 4 cents per cubic ft. Mr. Coppee says: "This dike, when finished, was the largest submerged spur ever constructed on the Mississippi River, and probably in this country."

The following description of the method of construction, taken from Mr. Coppee's account of the Greenville dikes built in 1889, "covers all the partly submerged spur types in use on the river."

Details of Dike Construction.

"The dikes consist of cribs made of poles and brush fastened by wire and spikes, having pockets formed in them in which rock is placed to sink them, and having for a foundation a mattress woven and sunk in the usual manner. They are placed normal to the bank line 500 ft. apart, and extend beyond the deepest water in channel next the shore.

"The purpose they are expected to serve is the protection of the bank immediately at the point they occupy, and the indirect protection of the intermediate spaces by deposits due to the eddy and dead water formed by their position relative to the swift current of the river.

"After an accurate hydrographical survey of the locality to be improved, a mattress, 290 ft. long by 290 ft. wide, extending about 50 ft. beyond the deepest water, was constructed on floating ways of willow brush and poles, wire and spikes, and launched into the river as woven. After being fastened by cable shackle lines to the shore above it was ballasted, and then sunk in the usual manner.

"The mattress was the foundation for the main body of the dike which was formed of cribs. The dimensions and general form of cribs were governed by the profile of the bank immediately at the point where the dike is located. The

dike under consideration contained but two cribs, the lower one 212 ft. long by 32 ft. wide and 8 ft. deep. The longitudinal axis of the cribs was 90 ft. below the upstream edge of the mattress. The dike was finished with as nearly a uniform surface as possible, having a slope of 4 to 1 from the river end to the top of the graded bank. The cribs were each right angular prisms in general form. Where 4 or 5 were required, the top one was 16×8 ft., the next 32×8 ft., the next 48×8 ft. and so on, the last one sometimes being constructed to conform to the irregularities of the bottom, but having a uniform top surface.

Details of Crib Construction.

"In constructing the crib a frame of poles and willows was laid on the floating ways on which the mattress was constructed in 8 ft. squares to the required length and breadth. On this frame layers of brush, both longitudinal and transverse, were placed, and on these another frame similar to the first, then other layers of willows followed by a frame, and so on until the crib had attained a thickness of 3 ft. Then the frames and intermediate layers of brush were thoroughly sewn together with No. 12 wire and 9 in. spikes, wire being left projecting far above the last frame to fasten the lower to the upper crib work. When the construction had reached this stage, the partly finished crib was launched from the mat barge and placed over the mattress on which it was to rest. It was then fastened by lines to the mooring barges which held it in place, and also connected with the shore by shackle lines leading well up the river.

"At the intersection of the frame poles 8 ft. apart, upright posts 9 ft. high were then securely fastened, and to these, as well as to the lower frame, the crib was built, pockets or compartments being formed in each 8 ft. square, of the shape of an inverted frustum of a pyramid, by dropping back one pole as each layer of brush was laid above the bottom 3 ft. foundation. When finished the crib was 8 ft. deep with pockets 8 ft. center to center about 5 ft. deep, and each capable of holding about 3 cubic yards of loose rock. The whole crib was securely held together throughout with spikes, wire and $\frac{3}{8}$ inch cables.

"The process of sinking was practically the same as in the case of the mattress. After the crib was securely fastened to the bank by cables placed carefully over the mat in the desired position, and after being checked up well by slip lines to the mooring barges, rock was thrown into the pockets until they were filled. When the weight had considerably more than overcome the buoyancy of the structure, the strain on the lines being very great and the crib in a sinking condition, then the slip lines were rendered slowly, care being taken to keep the strain uniform until the crib settled in its place on the mattress.

"In the case of the second crib, it was built 16 ft. narrower as before stated and sunk in the same manner on top of the first one, thus forming a sill 16 ft. high.

"After the mattress was constructed and sunk and before the cribs were started, the portion of the bank above the mat and water line was graded to a

slope of 4 to 1, preparatory to covering it with a revetment of willow and stone which was connected with the submerged mattress.

"After completing the grading the revetment was laid ; first, a framework of poles in 8 ft. squares, then two diagonal layers of brush placed on it, then another framework corresponding to that below and the entire mass tied together securely with wire and spikes. On this stone was laid close enough to hide the brush.

"When the revetment was finished and the mattress and submerged cribs sunk, the upper end of the latter was joined to an upper bank crib which carried the regular slope of the top surface of the dike to its intersection with the upper bank.

"This upper bank crib, though constructed on the ground, was in form similar to those made on the ways and formed but the continuation of the sub-aqueous slope.

"The total cost of the dike was :

Foot Mat	...	...	$3830·00
Crib No. 1	...	...	1699·00
Crib No. 2	...	...	872·00
Revetment	...	...	3168·00
Shore Crib	...	...	93·00
	Total	...	$9662·00

"DETAILED STATEMENT OF COST OF DIKE NO. 2, GREENVILLE, 1889."

Foundation Mattress 290′ × 290′ = 84,100 *sq. ft.*

Materials.	Amount.	Cost per unit.	Total cost.	Amount per square.	Cost per square.
Brush, cords	553	$1·27½	$705·07	$0·657	$0·84
Poles, cords	141	1·47	207·97	·168	·25
Stone, tons	767	1·95	1496·65	·912	1·78
Wire, coils	34	3·37	114·58	·040	·14
Cable, coils	6	42·27	253·62	·007	·30
Spikes, 6″, kegs	4	3·25	13·00	...	...
Spikes, 9″, kegs	5½	3·12½	15·63	·001	·03
Staples, kegs	1¼	5·00	6·25	·001	·01
Total Materials	.....	.....	$2,811·77	.....	$3·35
Labor hours	5,630	16	$900·80	6·69	$1·07
Sailor hours	737	16	117·92	0·88	·14
Total labor ...	.....	.....	$1,018·72	.....	$1·21
GRAND TOTAL ...	.....	.....	$3,830·49	.....	$4·56

CRIB No. 1, 212 × 32 × 8 feet = 54,272 cubic feet.

Materials.	Amount.	Cost per unit.	Total cost.	Amount per 100 cubic feet.	Cost per 100 cubic feet.
Brush, cords	228	$1·27½	$290·70	$0·420	$0·54
Poles, cords	100	1·48	148·00	·184	·27
Stone, tons	324	1·50	486·00	·597	·90
Wire, coils	32	3·37	107·84	·058	·20
Cable, coils	2½	42·27	105·67	·005	·20
Spikes, 6," kegs	2¾	3·25	8·94	.....	.....
Spikes, 9," kegs	7¾	3 12½	24·22	·013	·05
Total Material cost ...	.. ...	.....	$1,171·37	.....	$2·16
Labor hours	2,686	16	429·76	4·95	0·79
Sailor hours	610	16	97·60	1·12	0·18
GRAND TOTAL ...	.....	.....	$1,698·73	.....	$3·13

CRIB No. 2, 170 × 16 × 8 feet = 21,760 cubic feet.

Items.	Total cost.		Cost per 100 cubic feet.
Total materials	$605·79		$2·78
Total labour	265·76		1·22
TOTAL ...	$871·55		$4·00

REVETMENT 230 squares.

Brush, 325 cords; poles, 45 cords; stone, 649 tons; wire coils, 22; spikes, 6-inch, ½ keg; spikes, 9-inch, 3 kegs. Total materials cost $1,774·38; cost per square, $7·71. Labor cost, $1,393·44, or per square $6·08.

Grand Total Cost, $3,167·82, or per square $13·77.

LAND CRIB 3,000 cubic feet.

Total Cost of Materials, $60·37; per 100 cubic feet, $2·00.

Labor Cost, $32·32; per 100 cubic feet, $1·08.

Grand Total, $92·69, or per square, $3·08."

New Orleans Spur Dikes, 1890.

In the lower portion of the river this kind of protection is well adapted to the prevailing conditions, and some very large and heavy dikes have been built on the New Orleans front. Of several built in 1890, one is spoken of as the largest ever placed in the river.

In that year the dikes constructed there were changed from purely submerged dikes to a form somewhat similar to those used at Memphis and Greenville. "This consisted in carrying the dike above

low water by connecting it with an earthen levee with a crown of 10 feet and slopes of 3 to 1, the bank being first graded to a gentle slope. On this levee rock was placed to a thickness of 9 inches, forming a pavement covering the levee and extending 20 feet above and 50 feet below it. (*See* Fig. 4, New Orleans Dikes.)

"The large dike referred to contained about 3,400 cords of willows, 80,000 ft. of lumber, 2,000 tons of rock, 5,500 pounds of wire, 60 kegs of nails and spikes and 8,000 lbs. of iron rods and chain. Its length was 430 ft. and height 60 ft. The depth of water at its outer edge was 250 ft."

The cribs were constructed of sawed lumber frames in place of rough willow frames as in the upper river work, and in some cases they were five and six tiers high. Sketch cross sections of two of them are given opposite.

The average cost of these dikes excluding administration, repairs, etc., was $7·15 per square for mattress work, and 3·06 cents per cubic foot for crib work.

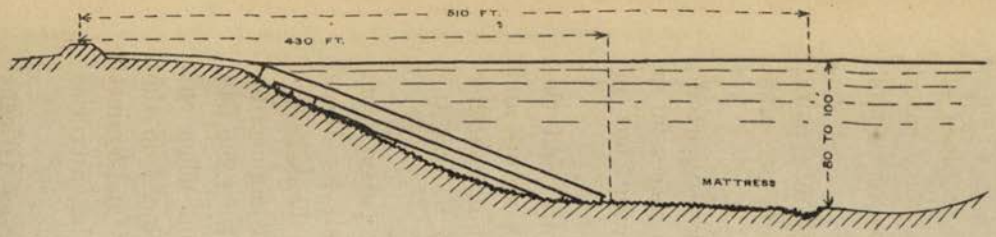
In 1893 the officer in charge of the third district reported: "Spur dikes without intermediate revetment have been successful in some straight reaches and in concave bends of large radii, but in abrupt bends the dikes alone are only locally effective."

Mr. Coppee says: "Where the bend is very abrupt and the bank sandy dikes are of little value. Where the bend is abrupt and the material clay and buckshot they should be placed not farther apart than 500 feet, and even then it may be necessary to protect the intervals between them."

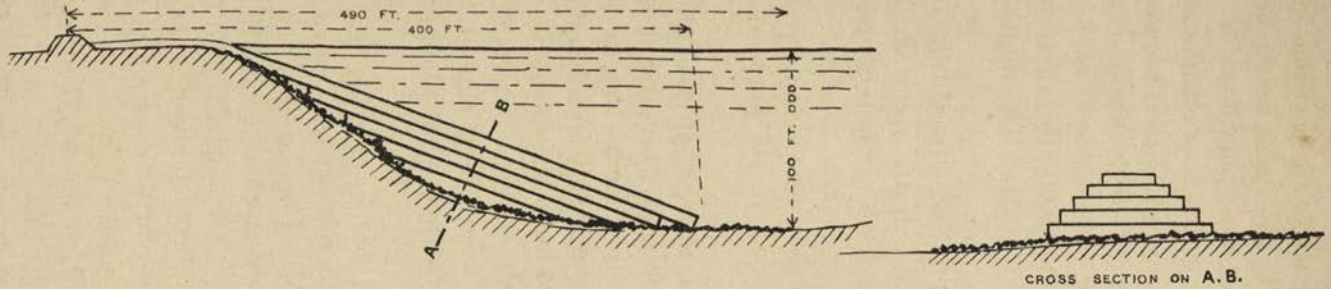
Mr. Coppee's Concluding Remarks.

Finally, in concluding his interesting and valuable paper, from which liberal extracts have been made for these notes, Mr. Coppee remarks that the bank revetment described, "is probably more extensive than any like engineering construction in the world." A mattress 300 feet wide by 1,200 feet long represents a superficial area of about eight acres, and when one realizes that this vast willow carpet over a foot thick is placed on the bottom of the river in depths of from 40 to 100 feet and against currents of from 5 to 8 feet per second, the difficulty of the enterprise will be appreciated.

"Though much of the revetment from Cairo to New Orleans has needed repairs from year to year and in some reaches has required



LONGITUDINAL SECTIONS OF DIKES



NEW ORLEANS DIKES

1890

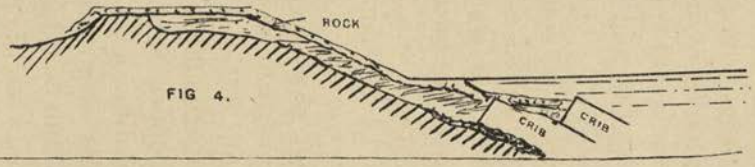
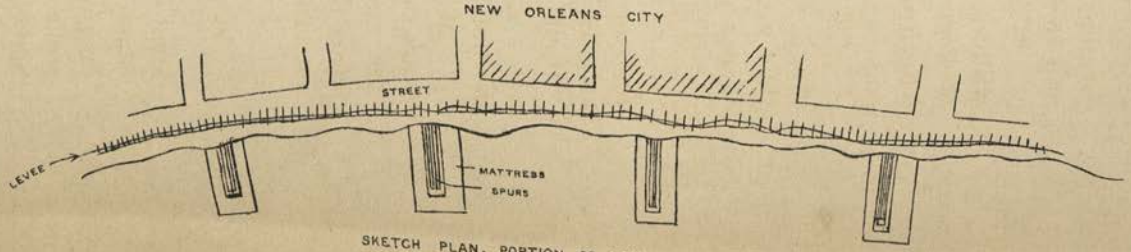


FIG 4.



SKETCH PLAN. PORTION OF NEW ORLEANS FRONT.

Plan Nº XIII.

renewal as a whole, it may be said to have been eminently successful in the protection of harbour fronts and the prevention of cut-offs and outlets, and fairly so in the control of bank paving and the resulting change in position and flow of the river.

"At some points where the material of the bank was friable and the currents very strong, the earlier forms of revetment proved too light and were entirely swept away, the shore line continuing to move back. Also considerable reaches of protection work needing repairs and reinforcement at the ends have been destroyed because of the lack of funds due to the failure of appropriations, etc. In the later work the results have been beneficial and satisfactory, and the loss but slight."

The spur protection of Greenville Harbour again suffered in 1894.

1894. Extensive caving in the bend above had destroyed a number of the spurs and threatened the entire system, as well as the town itself, with destruction. To meet this danger the protection of the caving bank of the bend had been undertaken, and the continuous revetment was further extended in 1894.

In the first two districts from Cairo down to 620 miles no spur dike works seem to have been built in this year. At New Orleans the spurs had given satisfaction except in one section where it was believed they had been located too far apart. Here the foundations for four intermediate spurs were laid and considerable areas between spurs, in all 744,000 square feet, were covered with mattresses and the upper bank revetted.

In 1896-97 the four spurs at New Orleans mentioned above were completed and several others added. In the

1896. latter year the mats and cribs were built on the willow grounds and thence towed to New Orleans, a distance of 150 miles.

At Elmot Landing, 160 miles below Cairo, where the bank had been previously protected in disjointed lengths of continuous revetment and spur dikes, a bad pocket, 650 feet long by 250 feet deep, was cut out of the bank in 1896. In order to stop and break up the eddy a spur dike was constructed consisting of three tiers of brush and stone cribs founded upon a fascine mat of irregular shape. The width of the mat normal to the bank was 360 feet and its length 100 feet on the

shore side and 160 feet on the outstream side. Owing to the absence of suitable plant to make this mat of the required width of fascines laid normal to the bank line, it was constructed of fascines laid longitudinally.

The first or bottom crib was 273 feet long, 24 feet wide and 5 feet thick; the second resting on No. 1 was 260 × 16 × 4 feet; and the third resting on No. 2 was 232 × 8 × 2 feet No. 2 projected 37 feet inside the low water line, and No. 3, 39 feet, leaving 30 feet of No. 2 exposed. The bank was graded up the slope for a distance of 100 feet and protected with rip-rap, extra stone being piled around the ends and against the sides of the cribs to prevent cutting and undermining. The stone work extended up to above the 20 feet stage.

Giles Bend Spurs, 1897.

In 1897 a project was sanctioned for the protection of the Giles Bend (700 miles below Cairo) to prevent a threatened cut-off there. It provided for the construction of 14 spurs at a cost of $95,700, including care of plant, &c., and also some three miles of continuous revetment. The following extracts from the District Engineer's report explain the proposals provided in the project:—

"Interesting experiments are now in progress with a view to making some material much more economical than rock for sinking the cribs and mats, using as a basis the sand and clay found upon the banks of the river where these structures are to be sunk. These experiments so far give great promise of success." (The writer learns they were not so successful as expected.)

"The reduction in the cost of crib and mat construction secured this season, withother no less important economics in sight, coupled with the fact that the several systems of spur dikes in New Orleans harbour have, in the main, been successful in holding the banks protected, and that in no case have any spurs been actually lost or in need of excessive repairs, has satisfied me that at the present stage of the art of bank protection the most available method for Natchez and Vidalia is the spur dike system.

"The upper spur should be located at a point where the bank has little or no tendency to cave, and a sufficient sum of money should be held in reserve to prevent this spur from being flanked by the current, should any change occur in the regimen of the river which might cause such a tendency.

"Owing to the tendency of the point of caving to work down stream and also to the proximity of the bluff and the presence of a bed of indurated sandy clay near the foot of the bluff, which yields but slightly to the action of the current, I anticipate no serious difficulty in holding the upper spur of the system, though the works should never be left without a balance of ready money,

which could be applied to protecting this crucial point against any unforeseen attack."

"It is proposed to place the spurs at intervals of 450 ft., standing each one upon a foundation mat 150 ft. wide. This interval is about what experience has dictated at New Orleans, and it makes the length of bank, not directly protected by the mat, just twice as great as the portion that is.

"The foundation mat will be of the usual New Orleans type, 2½ ft. thick, and is to extend from the low water mark to a point on the bottom of the river 50 ft. beyond the foot of the slope. On the average this will require a mat 350 ft. long.

"Spurs will be built of two cribs, each 6 ft. thick. The upper one, 16 ft. wide, to extend from near low water mark to the foot of the slope; and the lower one, 24 ft. wide, to fill in the hollow of the curve of the bank in the usual way. This will not in all cases bring the top of the spur to a slope of 1 on 3, but in my judgment it is not necessary that it should, and if further experience should develop any necessity for doing so, a third crib can at any time be added where required.

"It is proposed to sink the mats and cribs with stone, or with any suitable substitute which the experiments now in progress may develop as having sufficient weight, permanence and ability to resist erosion. The estimates below are based upon the use of stone.

"As the slope of the bank is generally quite gradual in Giles Bend where these spurs are to be constructed, and the range of the river amounts to about 50 ft., it will be necessary to adopt some form of construction to protect the bank between high and low water, mats and cribs not being suitable, as they would rapidly decay. Earthen embankments revetted with stone have been tried for this purpose at New Orleans but have not proven satisfactory.

"In my judgment what is required in this instance is a type of structure which will check the velocity of the current in contact with the bank, but without stopping it altogether. By this means I should hope to prevent the formation of large eddies.

"With this end in view, I would propose to grade the bank on the prolongation of the axis of the spur; and on the slope so formed drive a line of 12 or 14 in. piles about 6 in. apart in prolongation of the spur, cutting them off at a height of 12 ft. above the ground and bolting their heads firmly to a couple of string pieces. To prevent the small eddies and rapid currents which will be formed between and around the piles from cutting away the bottom in the immediate vicinity, it is proposed to pave the bank with stone for a distance of 25 ft. above and below each pile dike.

"The average field cost of each spur including the shore connection, will only amount to $5,500; assuming that each spur protects 450 ft. of bank this

protection is only estimated to cost $12·20 per running foot of bank, no allowance being made however for the cost of plant."

Success of Spur Dikes on the Lower Reaches.

The general type of the bank protection used at New Orleans is described by the Commission in their 1896 report as "Sloping Submerged Spurs of Brush and Stone resting on broad footmats and connected where necessary by revetments." The New Orleans project was commenced in 1882. "It was intended to arrest caving in the concave bends of that part of the river along which the city of New Orleans is built, from the upper side of Nine Mile Point on the right bank to some distance below the U. S. Barracks on the left bank, a distance of about 16 miles, comprising four bends. Partial work has been done on only three of the four bends, as the smallness and irregularity of the appropriations has compelled the policy of first applying protection work where the greatest emergency existed at the time, instead of allowing an orderly and systematic progress from the head of the reach down stream. . . . Such parts of the work as have been constructed are entirely successful in arresting the local caving and are now in good condition."

Opinion of Mississippi River Commission on the general use of Spur Dikes in the Upper Reaches of the River.

On page 3421 of their report for 1896 the Commission state: "There are methods of protecting caving banks besides the continuous mattress revetment. Among these that known as the spur-dike revetment is the best and most widely used. This form of revetment has been tried at some places on the Lower Mississippi under the recommendation of the Commission, the most important of these places being at the harbour of New Orleans. The spurs in all these revetments were constructed of brush, mattresses and stone. Full descriptions of them will be found in former reports of the Commission. But sawed lumber could be used in the place of brush; and of this the possible supply is ample. Some forms of spur have also been suggested, but not tried, involving the use of sawed lumber alone.

"It is not to be doubted that there are some situations in which spur-dike revetments can be employed with success, but for use on the soft banks and in the rapid currents which characterize the greater part of the river between Cairo and Vicksburg (mile 600), the Commission does not consider that form of bank protection as a safe

and reliable one, certainly not one to be constructed on a large scale and at the hazard of great loss if it should fail, without some years of careful experimentation."

1898.

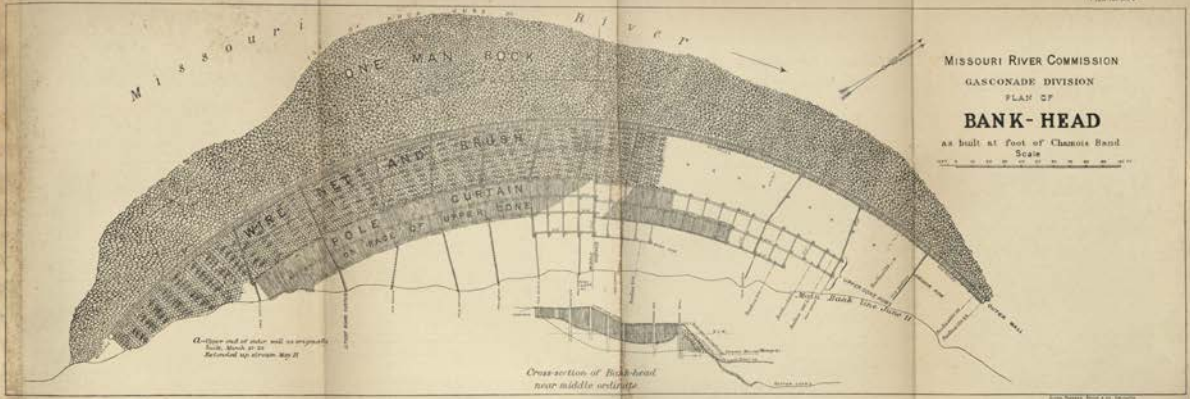
The clear expression of opinion by the Commissioners on the inadvisability of using spur dikes in the first 600 miles below Cairo, where the banks are soft and the current rapid, leads one to ask, what success was reached in the Giles Bend dikes with the experimental pile work up the bank in continuation of the spurs? The writer saw these works with the Commission on their low water inspection in December 1898, and made special note of the violent cutting occurring just below each dike. The piles collected drift, which caused a heading up of the water and created a violent eddy around each dike, ending with a strong direct attack on the bank below it. An attempt was made to get a photograph of the general bank from the steamer as it was a most instructive experiment in spur dikes in that reach of the river but owing to rain it was not successful. The writer, however, noted that the pile extension of the spur in the conditions there prevailing might be classed as a failure. He now learns that after their inspection of this work, which is spoken of as having been experimental, the Commission passed a resolution, in effect, directing the cutting down of the piles as low as possible, the sinking of mats between the spurs, the protection of the banks between the spurs with continuous revetment, and further that no more spur dikes are to be built at the Giles Bend without express orders.

Latest New Orleans Work.

On page 3797 of the Chief of Engineer's report for 1897 will be found a brief history of the New Orleans work from the earliest time, and also a description of the present methods and cost for several of the later years. Mr. Douglas, the writer of it, mentions that one of the principal objections to both fascine and woven mattresses is that they must be built on the spot where they are sunk. With the frame mattress it can be built at any point above the locality where it is to be sunk, where willow or brush can be obtained. Amongst other interesting facts it is stated that 192,000 square ft. mattress and 606,720 cubic ft. of cribs were built and placed in eight spurs in 93 days. The mattress cost $6\frac{1}{4}$ cents per sq. ft. and the cribs 3 cents per cubic ft. He gives the details of cost on pages 3800-3801.

The plant employed on the New Orleans work includes the following :—

Tug		valued at	$5,000·00
Quarter boat		„ „	8,000·00
Outfit		„ „	2,000·00
Warehouse barge with outfit ...		„ „	4,000·00
Mooring barge		„ „	4,000·00
Dock		„ „	4,000·00
11 barges at $3000 each ...		„ „	33,000·00
Wire rope and other appliances ...		„ „	5,000·00
Rock, lumber, mats, &c. ...		„ „	10,500·00
TOTAL PLANT OUTFIT ...			$75,500·00



MISSOURI RIVER COMMISSION

GASCONADE DIVISION

PLAN OF

BANK-HEAD

as built at Foot of Charnois Bend

Scale

BANK HEADS, MISSOURI RIVER.

In 1896 an experimental device called a Bank Head was built on the Missouri River at the foot of Chamois Bend, Montana, 3,850 feet below the end of the revetment. Although subject to a very severe test by a change in the line of the approaching flow, due to other influences some two miles up river, the structure stood well. It is reported to have so far accomplished the object for which it was built, in that the length of bank above has not receded and the original bank below for a length of 1,800 feet has been protected. The cost of the bank head was $11,265. The 5,000 linear feet of revetment which it replaced would have cost $35,000. The work was commenced on March 13th and practically completed by March 26th. This is another illustration of the facility with which large river works are carried out on the Mississippi and its tributaries.

Details of Construction.

The arrangement is shown on the drawing given opposite, taken from the Chief of Engineer's report for 1897, from which also the following description is extracted.

It consists of segments of the frusta of two cones, having a common axis, the lower one resting against the bank and on the bottom of the river, its top cut by a plane 6 feet above standard low water and developing an arc of a circle 724 feet in diameter and having a middle ordinate from the bank line of about 90 feet; the upper frustum resting against the bank and on the lower one developing an arc of a circle 640 feet in diameter, and from a common centre.

In all 608 piles were driven, 446 in the outer wall, 29 in the anchor row, 9 in the bank row, 109 in the upper cone frustum and 15 for outside temporary anchorage. The piles were driven to an average penetration of 22 feet. The distance apart of piles in the outer wall was 3 feet centre to centre, and brush was introduced between them vertically and as wattling with a view to produce a practically water-tight wall.

Altogether a quantity of 3,970 cubic yards of one man rock was used, a thickness of $2\frac{1}{2}$ feet being kept at the middle ordinate and the balance being disposed below in diminishing section.

In order to fill the space between the outside circle of piles and the upper cone frustum with flood deposits, 1,490 odd lineal feet, or about 32,000 square feet, of curtains were built as shown on the sketch. One of these on a line 30 degrees upstream from the middle ordinate was a tight curtain made of 1 inch boards. The horizontal curtain extending from the outer wall to the base of the upper cone frustum was made of wire netting, the meshes of which were partly filled with brush. The netting was supported on wales and $\frac{3}{8}$ inch wire strand.

It was expected that the bank head would permanently hold the bank at that point, and that after a certain amount of recession the stretch of free bank above it would become stable. The form given the structure was thought to be such as would avoid at all stages the formation of violent eddies which are so marked when the ordinary solid dike is used and which develope with such persistency below the outer ends of exposed permeable dikes after they have been subject to one or more heavy floods. The expectations were fulfilled, but, as afterwards found, a higher velocity and a greater heading up were experienced than were anticipated. They were due to a change in the channel above—two miles upstream—where an accretion threw the channel across the river, whence it returned immediately above the bank head changing the direction of flow about 50 degrees in 2,000 feet length

In these circumstances the attack on the structure was very severe; it amounted to nearly the full force of mid-stream flow, and naturally the head accumulated was much greater than if the flow had continued tangential. The head of water was fully explained by the direction of attack as were also the flow around the structure and the eddy resulting from the great velocity. There was a measured slope of 0·68 feet at the bank head from the upper end of the outer wall to a point 30 feet below the middle ordinate, and a negative slope of 0·10 from there to the lower end of the structure on June 7th. Notwithstanding this severe and unexpected attack, occasioned by the change of channel above, the structure showed its stability.

If it had not been built it is probable that there would have been a great recession of the bank at that point and for some distance below. During the first period that the outer wall was submerged there was no eddy, and for a long distance below the structure and for some distance out from the shore the water was dead, the outer line of the

dead water being a curve of large radius that was almost tangential to the outer wall near the middle line and which came into the shore at a point 1,800 feet below. In this area there was considerable deposit.

The cost was as follows:

Pile Driving:	Labor ...	... $798·22	
Piles:	Pine 9,444 l. ft. ...	... 1,463 82	
	White oak 2,308 l. ft.	... 286·19	
	Water oak 7,216 l. ft.	... 649·25	
	Cypress 4,239 l. ft.	... 520·12	
	Coal & supplies ...	... 82·89	$3,800·49
Waling, Bracing, and Curtains:	Labor ...	... $663·85	
	Lumber 12,667 B. M.	... 231·87	
	Brush & poles 56 cords	... 95·20	
	⅜ inch galvanized wire	... 40·65	
	Fastenings, bolts, spikes, &c.	... 300·22	$1,331·79
Rocking:	Labor		
	Labor	.. 332·28	
	Rock 3,970 cu. yds.	... 4,198·00	$4,530·28
Subsistence:			583·20
Tow-Boat Service:			1,018·63
			$11,264·39

It should be mentioned that the reach where this bank head was located had a long easy curvature; and further that the channels of the Missouri are being steadily improved by the construction at considerable expense of dikes or permeable wing dams. Their construction helps to divert or modify an attack on a point, by changing the direction of the upper channel, thus possibly saving the bank protection from entire destruction under a violent attack.

Colonel Stickney's Theory on use of Bank Heads.

Appendix 1 of the Chief of Engineer's Report for 1897, part 5, is a paper by Colonel Stickney on Bank Protection, in which he gives his theory of Bank Heads, or the holding of selected points in preference to continuous revetment on river banks. He premises his paper by stating he is convinced of the impracticability of protecting the banks of the Mississippi for hundreds of miles by continuous revetment.

His objections to continuous revetment are briefly :

The great extent of the work.

The great first cost and heavy maintenance charges.

The difficulty of watching and keeping in repair the long line of submerged work.

The scanty supply of material (brush) required for such work.

The probability of its eventual destruction.

At New Orleans submerged spurs have been tried, says Colonel Stickney, but this did not fully carry out the idea of holding detached points at considerable distances apart, leaving the bank between the points to be attacked by the current till it had receded to a position where its distance from the general flow of the river would be such that the velocity of flow along the retired bank would be below that necessary to erode the material of which the bank was formed. "The more recent study of the matter has led me to the belief that the intervals between fixed points should be from 7,000 to 8,000 feet which would permit of much more substantial structures and yet reduce the cost per mile of bank."

He discusses the matter at length and illustrates his paper by diagrams. He concludes that if two points in a bank be made fixed points, the bank above the upper point being in a stable condition, the bank between the points will not recede by scour so far as to form a concave bend of much less radius than 5,000 feet except in the vicinity of the lower point.

He then finally considers what kind of structures can be built that can reasonably be expected to accomplish the desired purpose and be permanent.

The following conclusions are given as results of experiments on a small scale on the Missouri River :—

1. That if a sufficient thickness of stone is placed on the slope of a bank of the river where banks and bed are subject to scour, the subaqueous slope subsequently formed by scour will be almost entirely in advance of the toe of the original slope and the surface of it will be covered by the stone falling on it.

2. That having reached the limit of maximum scour the slope will become stable even on a soft bottom.

3. That water flowing with considerable current will pass around a fixed curve of 300 feet radius without producing violent eddies.

Bankhead, Chamois Bend. View taken August 7, 1897, looking Down Stream.
Construction Party with Pile Driver, are about to commence extending the upper arm to a junction with Caving Bank.
Stage of River 1.75 feet above standard low water.

Colonel Stickney gives his proposed bank head section and an estimate of its cost in 60 feet depth of water, with stone 2·42 feet thick, allowing for scour of 100 feet in depth along the front.

The total of his estimate is $67,000.

This paper is very interesting and instructive, but, though bank heads have been experimented with on the Missouri River, they have not yet been tried on the Lower Mississippi.

Bank Heads, Missouri River, 1898.

The annexed plate shows the condition of the Chamois Bend Bank Head after the high water of 1897. The outer wall was then extended 44 feet, but after its completion the bank above the structure still continued to recede, and when the writer inspected the work in March 1899, it was apparently still slowly receding and appeared much as shown in the plate but with the right bank in the foreground further receded.

It was originally expected that the main flow of the river would continue to closely follow the right bank from some distance upstream down to the bank head. A change however occurred, as before stated, and, as the work was experimental, endeavour was made by auxiliary works to restore the channel and to expose the bank head to the conditions on which its favourable action was predicted. The bay in Chamois Bend was masked by dikes and reversed abatis placed across chutes, but without succeeding in entirely restoring the original conditions. The bank has receded for a distance of about 1,000 feet above the bank head back of the theoretical line ; indeed, the curvature just above the bank head has a radius of little more than 1,000 feet. The structure however stands well the attack to which it is subjected, though a further extension of the outer wall seems advisable. Mr. Waters Fox, the District Engineer, expresses the opinion that so long as the piles retain their strength he doubts if the structure would sustain any damage if no work was done to it. He says : " Experience shows, however, that a bank head is liable to be subjected to attack by direct flow at any point along its outer wall, and therefore the supply of rock should not be diminished below the directrix as it was in this structure."

Since the construction of the Chamois Bend Bank Head, several others, eight or nine in all, have been built on the Missouri River, most of them being completed before the high water of 1898.

Different designs have been tried, and the action of the river watched on each. Notable changes which were made were the omission of the pile work altogether and the placing of the rock in trenches on the natural bank in such quantities as would eventually give the thickness of protection required as the bank eroded and the stone slipped to its natural slope. Most of these experimental bank heads have stood fairly well, but experience seems to point to the advisibility of retaining the piles and to broadening the berm to form a natural beach between the two cones. The tight-board curtain referred to in the description of the Chamois Bank Head has no advantages, in fact it was evident on inspection that the ordinary curtain of poles spaced two or three inches apart has fulfilled the requirement for which it was built.

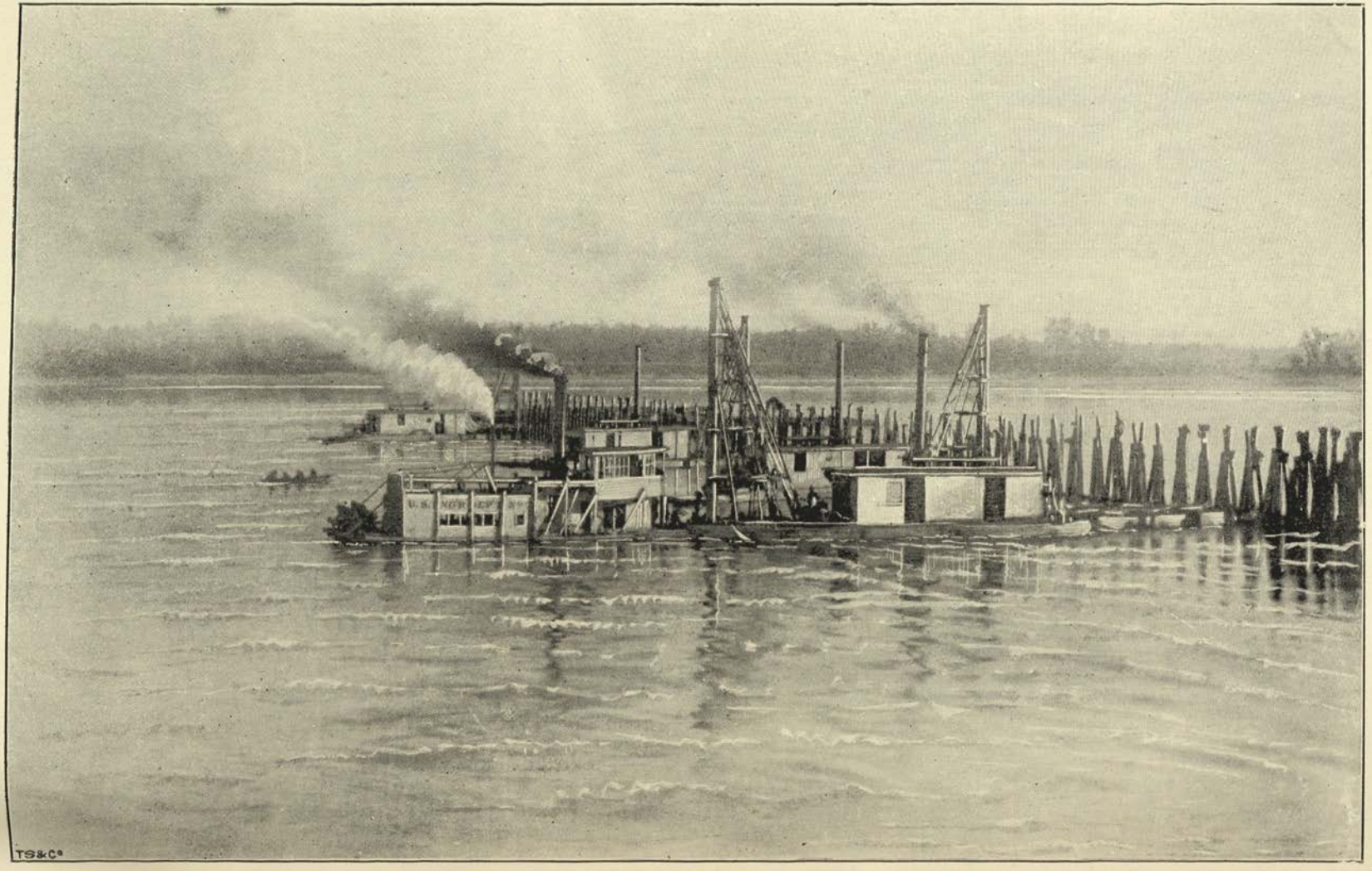
The latest experiment is the placing, in extension of the bank head, of submerged dikes or sills made of "burrs" of brushwood, to cause deposit of silt in the bed of the river and to prevent the scouring of a trench around and outside of the toe of the bank head.

The Missouri River Bank Heads are still in the experimental stage, though Colonel Stickney believes that they show good promise of success. His development of them will be watched with great interest. If points on the river bank can be effectually and permanently held by such isolated works a large reduction in cost in bank protection may be expected, and one of the most difficult problems in river engineering will have been solved.

BANKHEAD CONSTRUCTION.

Showing Bankhead nearing completion. Looking Downstream.

Bankhead Construction. Showing Bankhead practically completed. Looking down Stream.



Hurdle Dike on the Mississippi.

CHAPTER VII.

Channel Contraction Works—Missouri River Improvements—Sill Dams.

CHANNEL CONTRACTION WORKS.

Channel Contraction Works.

THE Lower Mississippi from Cairo to the Passes is under the control of the Mississippi Commission, but the length above, from the Ohio to the Missouri, is held as a separate charge by an officer of the U. S. Corps directly under the Chief of Engineers, U. S. Army. In this length of river extensive channel contraction works have been undertaken, and an attempt to describe some of them will be made.

Mississippi River between the Ohio and Missouri Rivers.

The original condition of the navigable channel was such that the natural depth at low water was in many places as little as $3\frac{1}{2}$ to 4 feet. Works were commenced in 1872 and continued for a number of years, consisting of dikes and dams of brush and stone which were built with the view of confining the low water volume to one channel. The object of the present project is to eventually obtain a minimum depth at low water of 6 feet from the mouth of the Missouri to St. Louis (16 miles), and of 8 feet from St. Louis to the mouth of the Ohio (178 miles). It contemplates a reduction of the river to an approximate width of 2,500 feet, the natural width being in places from 1 to $1\frac{1}{2}$ miles. The method principally employed is the closing of sloughs (slews) and secondary channels and the building up of new banks out to the line desired from the solid matter brought down by the river which is collected by means of pile dikes and hurdle work. The banks, both old and new, are revetted where necessary.

For the temporary improvement of channels through shoal reaches "portable jetties," tow-boats to stir up sand, one provided with jet pumps, and hydraulic dredges capable of removing from 500 to 1,000 cubic feet of sand per hour have been used.

Definition of Hurdle.

Major Handbury, Corps of Engineers, the officer at present in charge of this district, defines a hurdle as follows:—A "hurdle" is one of the many silt arresting devices that have been experimented upon in this country and elsewhere; the hurdle consists essentially of a row or of parallell rows of

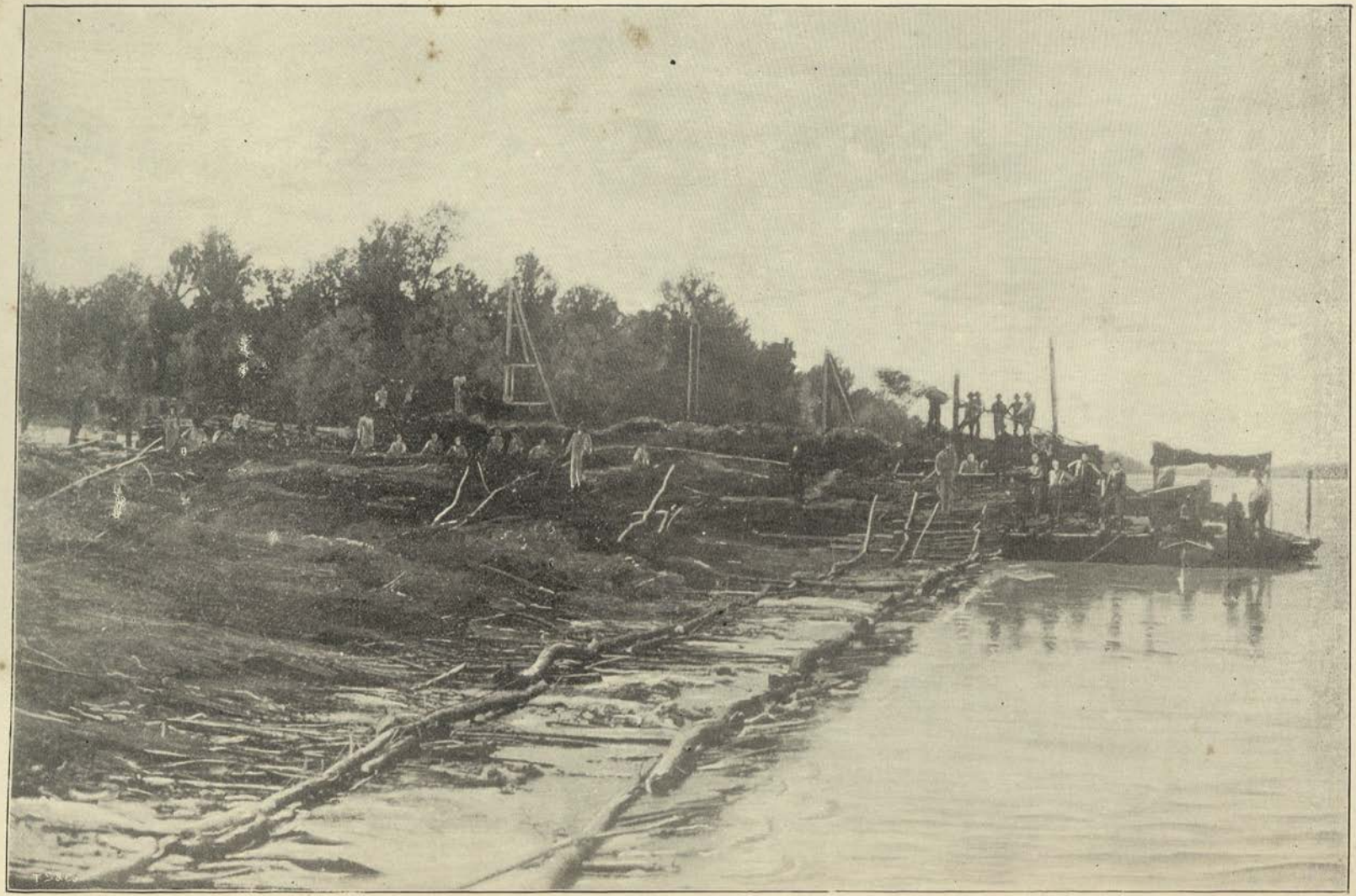
piling, the piles driven either singly or in clumps, the piling being connected lengthwise of the hurdle by wattling of fine brush, or by curtains composed of brush and lodged against the upstream side of one of the rows of piling; the whole forming a permeable dike through which the silt-laden current can pass, though with greatly diminished velocity, resulting in deposits of silt above and below the hurdles. These deposits are generally soon overgrown with willows or cottonwood, and after they arrive at sufficient height they can be revetted on their river front. To guard against scour of the piles a broad flexible mattress is first sunk on the line of the hurdle and through this the piles are driven.

Hurdles are being constructed of clumps of piles, three piles and upward to each clump. The piles are driven so that when their upper ends are drawn together by wire rope, they form a sort of pyramidal structure, the horizontal distances of the piles from each other at river bed level being 8 to 10 feet. The wire ropes are 14 to 18 strands of No. 14 galvanized iron wire.

The tops of the piles are kept about 20 feet above low water, excepting that in the curtain or wattling row the top of one pile of the clump is kept 25 feet above that stage in order to intercept drift and prevent it from crossing the line of the hurdle. The curtain or wattled row is braced by vertical, diagonal braces heeled against a row of clumps, spaced at such distances below as to make the angle of the brace about 45 degrees. The heel of the brace is held by a clevis passing around one of the piles of the lower clump with its pin through the brace. The top of the brace is bolted to one or more of the piles in the upper clump. (In the latest type this brace is omitted. *See* sketches further on.)

The piles are driven by means of the hydraulic jet and a hammer of about one ton in weight; they are spaced to represent about one per lineal foot of the dike. The completed curtain or the wattling, whichever is used, is generally carried up to about 20 feet above low water.

The mattress is from 60 to 130 feet in width, depending upon the depth of water and liability to scour. It is manufactured upon sloping ways of wattling brush upon poles spaced about 5 feet apart. Continuity is obtained by lapping the poles and tying them together with spikes and wire. The brush is spiked to the poles at the edge



Mattress Revetment between Cairo and St. Louis.

of the mattress and at other points, about one spike to every third pole. One cubic yard of stone per cord of brush is required to sink the mat.

The piles used in the hurdles vary in length from 25 to 60 feet. They are driven with the larger end down and penetrate the bottom about 15 feet.

At the shore end of the hurdle the bank is revetted for 300 feet, 200 feet below the axis of the hurdle and 100 feet above. In constructing the shore revetment a mat about 120 feet in width is sunk; the bank is then graded to a slope and covered with rip-rap.

Works of this description have been carried out at Piasa Island, Alton Harbour, St. Louis Harbour and many other points South. A breach in a hurdle at St. Michael's Landing, 27 miles below St. Louis, necessitated the construction of a new hurdle of length as much as 2,800 feet on the downstream side of the breach. Revetment works opposite Chester included a mattress 125 feet wide and 3,300 feet long the bank being protected as customary with continuous revetment works.

At Liberty Bend, 79 miles below St. Louis, where the bank is high and consists of sand and loam with an underlying stratum of quicksand, there are many examples of hurdles, hurdle dikes and revetment works of considerable importance and interest. At a point near the upper end of the bend a strong hurdle dike several hundred feet in length has been built out from the bank to prevent the outflanking of the revetment; and under the protection of this dike the revetment was commenced and continued downstream for nearly a mile and a half in length. On the other side of the river there are a series of hurdles set out nearly at right angles to the bank and slightly inclining downstream with reference to the channel, which were constructed for the purpose of narrowing the channel in that length.

Closing Sloughs.

At Powers Island, 143 miles below St. Louis, is a good example of the closing of a slough. This slough, known as Doolan's, separates the Island from the Missouri shore and formerly carried about half of the low water discharge of the river. It has been closed with a permeable hurdle 1,600 feet in length. The foundation was a mattress 150 feet wide, two-thirds of the width being laid on the downstream side of the line of piling. On the top of this was placed another mat, 50 feet wide, and in deep water third and fourth

tier mattresses, 25 feet wide, were laid just below or downstream of the piling to build up the bottom to an even cross section to receive the overfall of the dam. The bank at each end was protected by mattresses, 600 feet long by 150 feet wide; 250 and 350 feet respectively above and below the line of the hurdle. The banks were graded from low water up to a slope of 2 to 1 and then covered with a revetment of stone. The depth of water in the slough averaged 20 feet. "Piling was driven in three rows, 4 feet apart, of clumps, spaced 6 feet centres, of 3 and 4 sticks each. The clumps in each row were staggered with those in the adjacent rows. The use of the hydraulic jet was discontinued after driving two rows, as it was found to loosen those already driven."

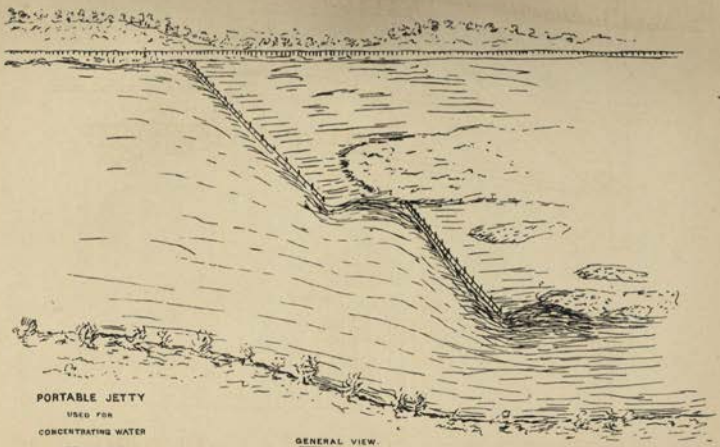
Jet Dredge.

A jet dredge or bottom sand agitator was experimented with in deepening channels a few years back. The outfit consisted of a dredge boat, quarter boat, pile driver, coal and pile barges. The cost of the dredge was $18,000 and monthly cost of working $2,650. It has, however, been superseded by hydraulic dredges which pump and deliver the sand through pipes at a distance from the cut of from 500 to 1,000 feet. The hydraulic dredge will be described further on under "dredging."

Portable Jetties.

Experiments have been made in the last three years with cheap devices designed to concentrate the water at shoal places and, by increasing its velocity, induce a scour that will improve the channel. The results have led to the adoption of a system described below.

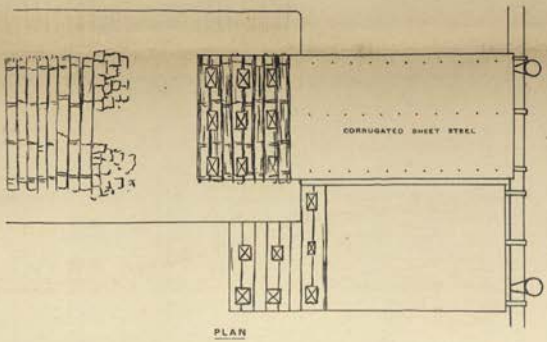
Having determined upon the direction that should be given the jetty to produce the best results, piles are driven firmly into the bed of the river along this line, at distances apart varying from 10 to 20 feet according to the depth of water and strength of the current. In extreme cases clumps of piles may be necessary. Along these piles, at a suitable distance above water surface, other longitudinal pieces are made fast by rope or wire. These are to support the upper ends of corrugated steel sheet panels, the lower end of which will rest on the river bottom. Each panel is 10 feet in width, measured in the direction of the jetty, and from 10 to 20 feet long or high depending on the depth of the water in which it is to be used. It is made of No. 14 U. S. standard gauge sheet steel, rivetted to three 5-in. I-beams 12½ lbs. per foot. Suitable links or clevises are provided for handling the panels.



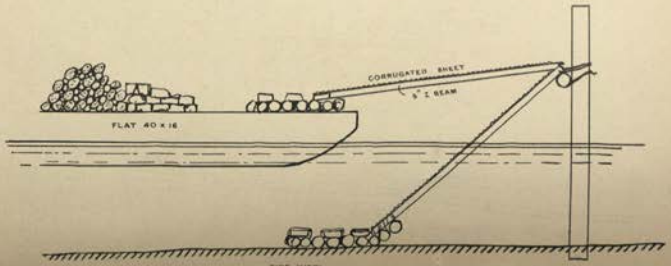
PORTABLE JETTY

USED FOR
CONCENTRATING WATER
UPON SHOALS.

GENERAL VIEW.



PLAN



SIDE VIEW

FILM NO. XX

To prevent scour along the lower edge of the panels, which would permit of their swinging through between the piles, a mattress from 8 to 10 feet wide of fascines laid side by side is tied to the lower edge of the panel and sunk with rock. At the end of the low water season the jetties are removed, the panels are taken up, cleaned and stored, and the piles are also removed to be used in future work.

The cost of these jetties, if abandoned, that is to say the whole first cost, including tools and plant and establishment charges, is \$6·06 per foot. Deducting value of recoveries and allowing for depreciation, &c., the cost is estimated at about \$4·25 per foot. It is stated by Major Handbury that a party with outfit on the ground should put in place as much as 400 feet per day.

A sketch of the arrangement is given opposite. Examples of such works are to be found on the Mississippi between the mouth of the Ohio and the Missouri Rivers, from the report (for 1897) on which the greater part of the above has been extracted. The estimate for the improvement of this length of river, as revised in 1883, was \$16,397,500. The expenditure to the end of 1897 was about \$7,000,000. The yearly expenditure of the current time is about three-quarters of a million dollars.

Suitability of this length of river for channel contraction works.

The length of river under consideration, *viz.*, from the mouth of the Missouri to the Ohio is particularly well suited for the use of hurdle dikes and such river contraction works. It is the first reach to take up the enormous load of sediment brought into it by the Missouri. Large deposits are easily induced where channel contraction is desirable to increase the depth. The extreme oscillation between high and low waters near the upper portion is about 36 feet; the low water slope averages 6 feet per mile, with a discharge of about 50,000 cubic feet per second; the high water discharge is from 800,000 to 1,000,000 cubic feet per second. Sand bars are numerous and crossings frequent, while their locations are constantly shifting. The contraction works so extensively undertaken during the last few years, combined with bank revetment, have been very successful, giving a great improvement in the navigation channels. Major Handbury speaks of them with great confidence, and his establishment, with the experience they have had, are now able to construct works not only of considerable magnitude but capable of holding the channel fairly permanently within the widths to which it is contracted.

Work of 1898.

In illustration of the magnitude of the works carried out of late years, the following examples of contraction and bank protection works executed in 1898 are given. They do not comprise the whole of the work of this district, but are merely some of the more important parts, exclusive of the dredging which latterly has been a special feature in the deepening of channels.

At Arsenal Island, to re-establish the shore upon the Illinois side and to force the river over to the Missouri shore, four hurdles aggregating 4,000 feet in length and about 1,700 feet apart were built out from the Illinois shore. They check the sediment carried by the river and cause a deposit in their locality which in time will be sufficiently high to be revetted and held permanently.

At Twin Hollows, Illinois, 14 miles below St. Louis, considerable revetment was built in 1882 and the following years. This was repaired in 1894. But a decided tendency to erode above and behind it during recent high waters has necessitated the repair of a length of over 4,000 feet.

In 1892 some 5,000 feet odd of the Illinois shore near Sycamore Landing, 46 miles below St. Louis, were revetted. Of this some 1,500 feet were repaired in October 1898.

The head of Moro Island, 58 miles below St. Louis, for a length of over a mile, was revetted to a 10 feet stage in 1895. Subsequent high waters eroded the upper bank and permitted the passage of a large volume of water between it and the low water protection. The bank was carried away for a length of 3,000 feet, cutting back to a distance of 400 feet. To restore the shore line to its old position, five short hurdles were built out about 650 feet apart, extending from the bank to the old mattress.

At the lower end of Ste. Genevieve reach, on the Missouri side, a soft sand bank over a mile in length is being held in order to preserve the alignment of the river channel. This is done by constructing a low water revetment. The lower end of this low water mattress for a distance of 1,600 feet is made of lumber 1 inch thick, 4 to 6 inches wide and 12 to 16 feet long. Mr. Curry, Assistant Engineer of this district, who has had long experience in construction, and who it will be remembered in the discussion on Mr. Coppee's paper on revetment defended the use of the woven mat in the upper reaches of the river, speaks with great confidence of this later method of construction with mixed lumber

and willows. The lumber is used because of the difficulty of obtaining sufficient willows for the extensive works in progress. Mr. Curry does not however offer an opinion regarding which description of mattress is most suitable for the lower river, as his experience has been on the upper length only. Though it is quite possible the fascine mattress is more suitable to the lower reaches, as proven by the experience of the Commission Engineers, he claims that the woven mat is successful in the length of river now being considered. It may be added that this mattress has been greatly strengthened of late years; wires, ropes, cables and spikes being introduced in considerable quantities.

At Anchor Landing, 80 miles below St. Louis, a length of some 7,000 feet odd of the bank was protected with mattress work and bank revetment.

At Hamburg, 120 miles below St. Louis, there is a difficult reach of water to navigate at low stages. The river divides into two channels and where they join below the island the width is excessive and troublesome to navigate on account of the numerous sand bars and shoals. The first step towards the improvement of this reach was the closing of the chute between the island and the Illinois shore. This was effected by the construction in 1898 of two permeable hurdle dams, one 2,860 in length across the head of the chute, and the other some mile and a quarter below of length of 1,200 feet. In the first hurdle the piles were driven in three rows 18 feet apart, with the piles of the middle row 6 feet apart, and in the other rows 12 feet apart for a length of 570 feet odd from the Illinois end. Thence the usual form of a double row of 3-pile staggered clumps was used to the bar line at the head of the island; a single row of 3-pile clumps was jetted across the dry bar to connect the head of the island with the double row of clumps. The Illinois end of the hurdle was protected by a shore mattress with revetment to about the 20 feet stage, while the island end was protected by revetting the bank with rock to prevent scour. Curtains were placed in front of the hurdle to a height of 8 feet above low water. The second hurdle was constructed as a double row of 3-pile clumps driven over the foundation mattress and reinforced in deep water by a third row of clumps. The clumps were connected by a longitudinal stringer dropped between the clump rows and fastened by wires. Curtains were also placed in front of this hurdle to the height of the 8-feet stage. The closing of this

chute by these permeable structures has already had a marked effect in increasing the depth of navigable water through the channel of the river at low water, and the high water has caused extensive filling above the head of the chute.

At Devil's Island chute a hurdle 1,200 feet in length was built across its head. The bank upstream of this is protected by revetment for a length of 1,600 feet and downstream for a distance of over 4,000 feet. In this locality two hurdles of 900 feet and 1,200 feet respectively were also built in 1898.

As already mentioned, a strong hurdle dam was built in 1897 across Doolan's Slough which separates Powers Island from the Missouri shore. This dam is reported to be successfully accomplishing the object for which it was constructed. Across the head of the slough and for some distance downstream there has been a large deposit of sediment. A heavy deposit of drift was left above the dam by the floods of 1897. This drift was sunk in place by putting a broad mattress over it and weighting it down with stone, which added greatly to the strength of the dam.

At Commerce Island, a hurdle was constructed extending down river across the head of the chute. It is 2,800 feet odd in length and, being in an exposed position, was made of great strength.

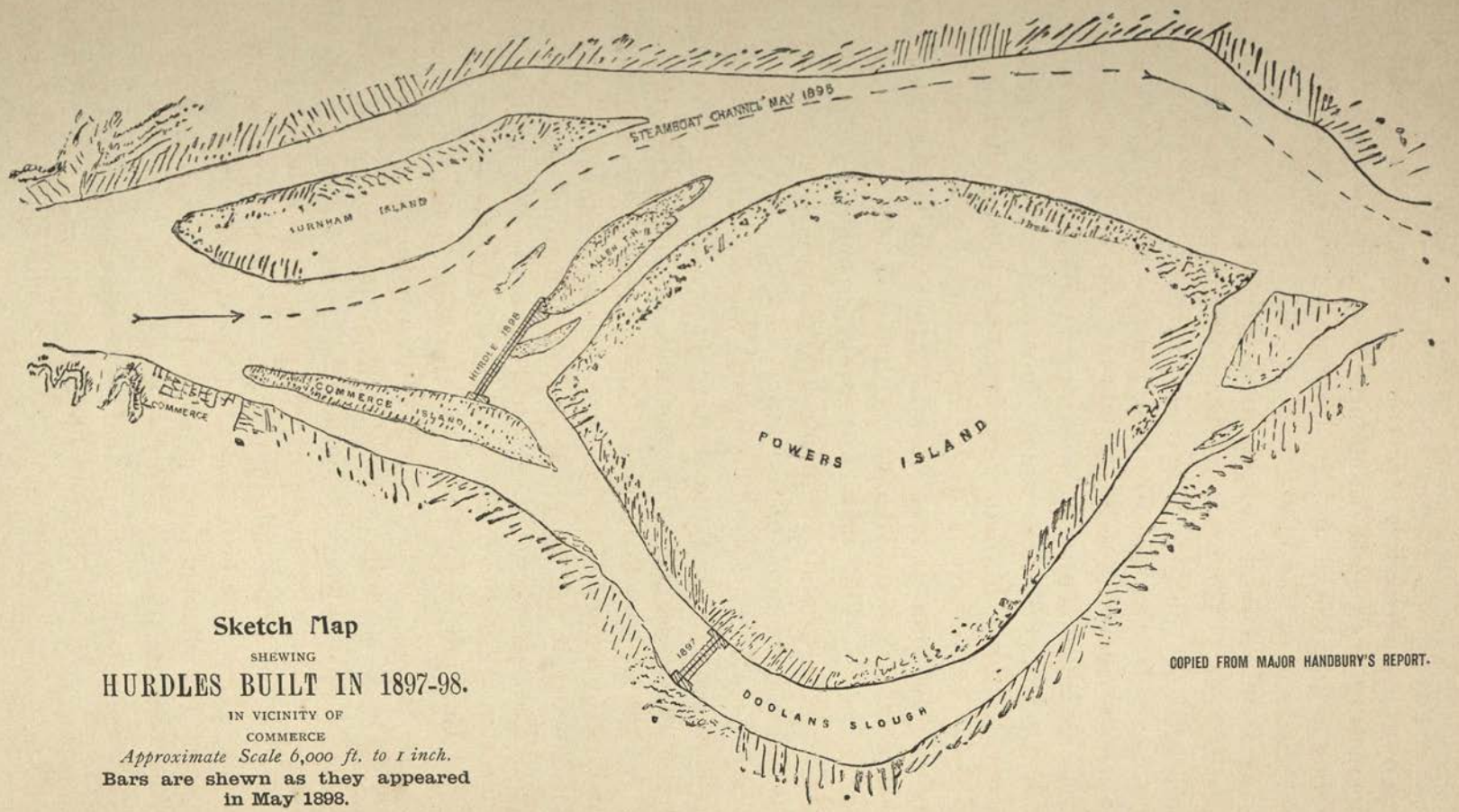
A sketch plan of the river showing the location of the Commerce Island hurdle and of the dam across Doolan's Slough, is given opposite and following it will be found a sketch map of the Ste. Genevieve reach. The latter is a good illustration of the method adopted in the location of hurdles designed to narrow the river.

Temporary channel improvement, 1898.

At Bushburg near Riverside the main channel is deflected across the river and returns again below Riverside, making four crossings from one side to the other in a distance of six miles. To assist the work of the dredge which was employed on this section, a portable jetty 1,100 feet in length was constructed on the upper side of the bar, inclining outward into the main channel. The combined action of the dredge and jetty resulted in deepening the channel for a length of 4,000 feet from 3½ feet on a 10-feet stage to 4 feet on a 3 feet stage.

Portable Jetties.

With the experience gained in previous years in the use of these jetties and having considerably strengthened them, rendering them more suitable for the duty they were



Sketch Map

SHEWING

HURDLES BUILT IN 1897-98.

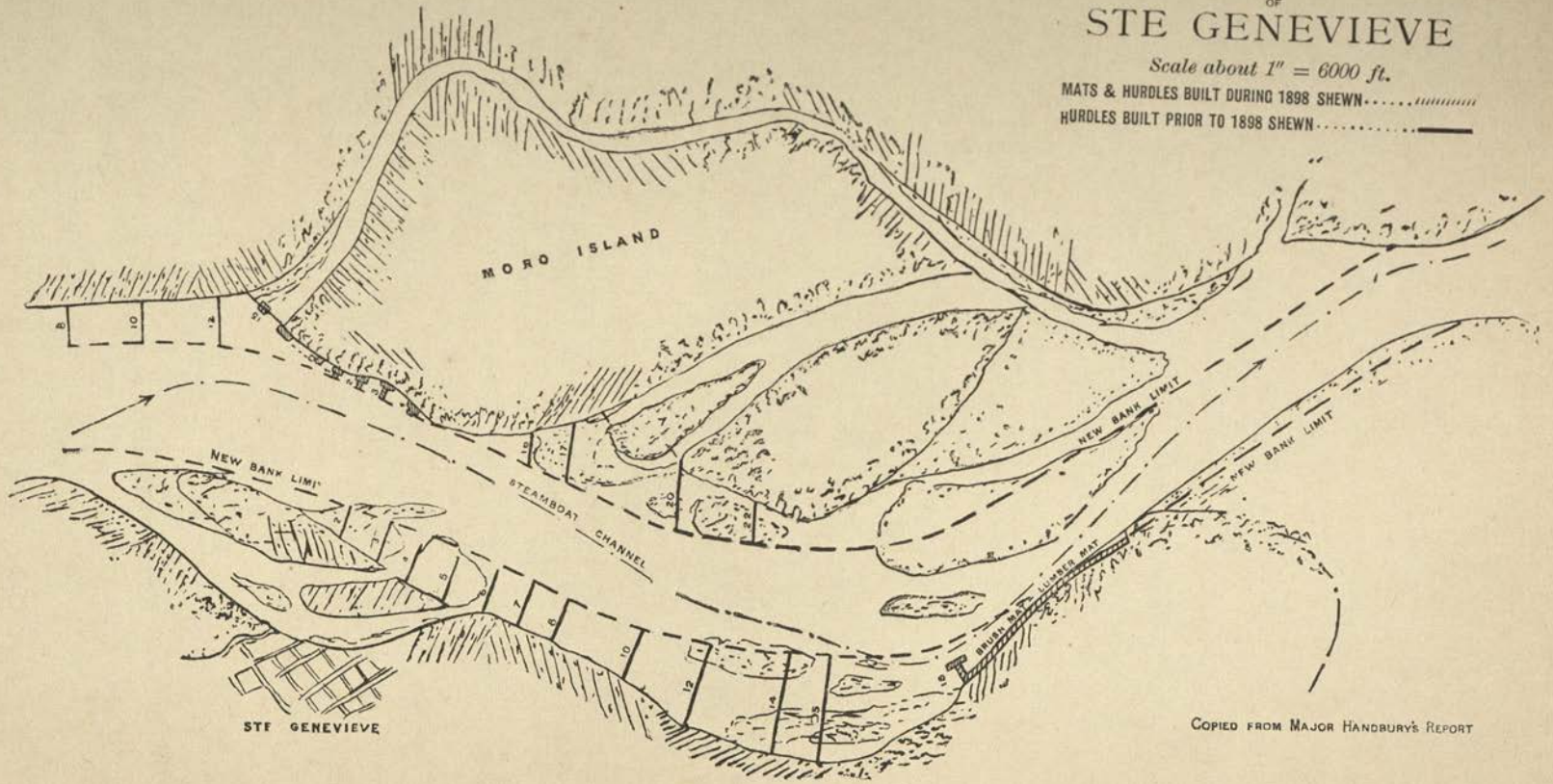
IN VICINITY OF

COMMERCE

Approximate Scale 6,000 ft. to 1 inch.

Bars are shewn as they appeared in May 1898.

COPIED FROM MAJOR HANDBURY'S REPORT.


Sketch Plan
IN VICINITY
OF
STE GENEVIEVE
Scale about 1" = 6000 ft.
MATS & HURDLES BUILT DURING 1898 SHEWN
HURDLES BUILT PRIOR TO 1898 SHEWN
MORO ISLAND
NEW BANK LIMIT
STEAMBOAT CHANNEL
NEW BANK LIMIT
NEW BANK LIMIT
BRUSH MAT
LUMBER MAT
STE GENEVIEVE
COPIED FROM MAJOR HANDBURY'S REPORT

called upon to perform, work of considerable extent and success in the placing of the jetties was undertaken in the 1898 season. Jetties were built at the following localities: Riverside, Harrisonville, Platin Rock, 76 Landing, Juden Creek, and Buffalo Island. They varied in length from 450 to 2,200 feet. "The total length built and removed during the season was 9,345 lineal feet, the jetty party took the field during the latter part of August and was withdrawn in December. It was in the field 97 days, of which 39 were employed in construction, 23 in removal, 19 in towage from place to place, and 16 were lost (Sundays, rain, &c.). The cost of putting this length of jetty out and replacing it in store was but $3·00 per lineal foot. This includes the proportional expenses for plant, repairs, deterioration, towage, office, engineer depôt, &c."

Major Handbury reports: "The jetties materially improved and maintained the channel at each of the crossings where they were placed, giving a navigable depth of 5 feet or more, although the river reached a stage of 1·2 feet below the standard low water."

Early Types of Hurdles.

Opposite next page are given sketches showing the development of the hurdle dike on this reach of the river. Fifteen years ago it consisted of a single row or rows of piles, braced transversely as shown, driven through a foundation mattress about 50 feet in width. This developed into rows of two or more "staggered" piles, the front row being braced as before, with the upstream pile of the front row of height extending above the general level of the rest in order to catch drift. This arrangement tended to save the general hurdle from destruction by the overflow of drift, as when it topped the higher piles or broke through them it merely sheared off their heads without necessarily destroying the rest of the structure.

Then followed rows, of different heights, of clumps of staggered piles. Finally in 1898, was adopted the system of rows of three and four pile clumps, driven close together with the clumps alternating and connected by longitudinal stringers, with or without curtains, the whole driven through a foundation mattress 120 to 200 feet in width.

The sketch showing "type of hurdles" is not an absolute standard but was designed as a general guide for the working parties in spacing and grouping the piles in different depths of water. It gives a fair idea of the general practice followed at the present time in the reach of the Mississippi between the mouths of the Missouri and the Ohio.

This note is also illustrated by plates of photographs presented by Mr. Curry, the senior Assistant Engineer in Major Handbury's office.

Materials used and cost of hurdle construction.

The quantities of work done in 1898 at Arsenal Island on four hurdles aggregating 4,400 feet in length, and at Hamburg Chute on two hurdles aggregating 4,085 feet, were respectively as follows:—

Materials.		Arsenal Island.	Hamburg Chute.
Piles driven	No.	4,532	3,294
Braces placed	„	*Nil.*	206
Stringers placed	„	239	58
Foundation mattress made & sunk	sq. ft.	616,532	622,055
Drift mattress	„ „	32,049	.....
Revetment placed	„ „	67,660	43,184
Curtains fabricated & placed	„ „	7,460	36,430
Buttresses built	No.	3	.....

The cost of these works are shown in the published accounts as under, it being noted that the figures include all expenses on account of tools and plant, office charges, etc.

Item.	Arsenal Island.	Hamburg Chute.
Labour, superintendence	$ 17,880	$ 15,877
U. S. Engineer's office, general charges	1,737	1,544
Plant and Materials	10,774	9,532
Surveys and Steamers	1,059	1,806
Steam tenders, barges, boats, and pile drivers	5,235	4,440
Tools, boarding outfit and subsistence	6,063	5,788
Brush	8,310	7,054
Piles	16,664	12,565
Stone	5,851	6,302
Rope, wire, iron, nails, spikes, lumber Oakum, coal, miscellaneous	1,854	2,582
Total cost of 4 hurdles of length aggregating 4,400 feet spaced about 1,700 feet apart, with buttresses at river end, protection at shore end, and with cribbed drift mattress	$ 75,428	.....
Total cost of 2 hurdles aggregating 4,085 feet in length, each hurdle consisting of 3 rows of clumps, with bank protection, etc.	.....	$ 67,493

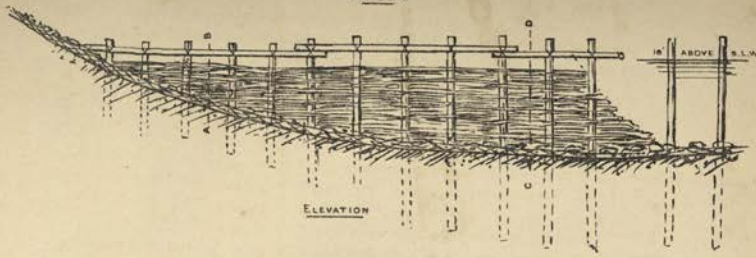
Subsequent to writing the above, the following tabulated statements of work, cost and rate per lineal or square foot of these and other works, posted to the end of December 1898, were kindly supplied by Major Handbury. (*Printed in part only.*)

EARLIEST TYPE OF HURDLE

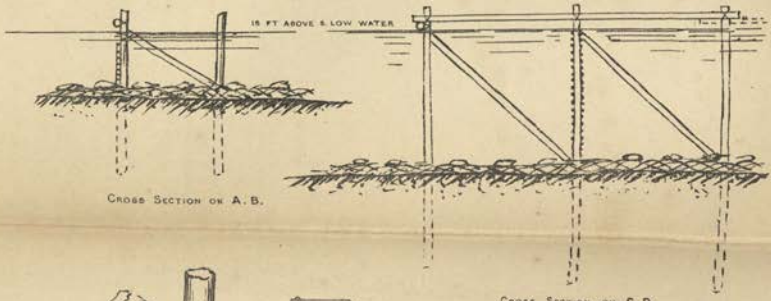
ROWS OF SINGLE PILES

Scale approximately

1 INCH = 12 FT.

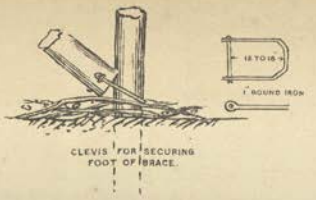


ELEVATION



CROSS SECTION ON A. B.

CROSS SECTION ON C. D.



CLEVIS FOR SECURING FOOT OF BRACE.

Notes.—For depths of 3 ft. or less only one row of piles was used.
" " 3 to 6 " two rows were used as at A B above.
" " 6 to 12 " three " " " " C D.
" " over 12 " four " " sometimes used.
" " 12 to 15 " the distance between rows was kept equal to depth of water.
" " below 12 " " " 12 ft. constant.
" " over 18 " cross stringers were used as shown at C D.

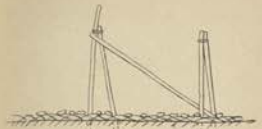
The foundation mattress was kept about 50 ft. wide.
Wattling was built in horizontal rows from bottom upwards.
Piles were usually driven to depths rather more than the depth of water at 16 ft. stage.
The bank was protected 100 ft. above and 100 ft. below the axis of the hurdle.
This information has been extracted from old reports.

E. F. DAWSON.

February 16th, 1899.

Plate No. [illegible]

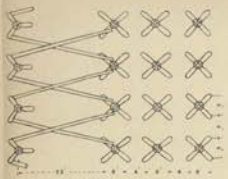
FIRST IMPROVEMENT ON SINGLE PILE ROW HURDLE



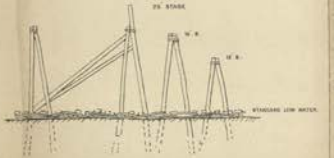
CROSS SECTION.

CROSS SECTION.

HURDLE OF FOUR ROWS OF 4 PILE CLUMPS STRENGTHENED AND BRACED DIAGONALLY.



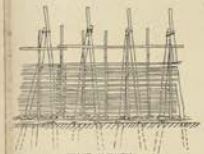
PLAN.



CROSS SECTION.

HURDLE OF SINGLE ROW OF 4 PILE CLUMP WITH MATTLED CURTAIN.

PLAN.

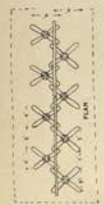


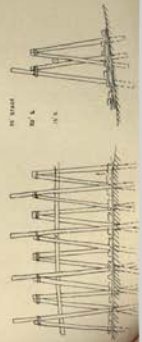
FRONT ELEVATION

CROSS SECTION.

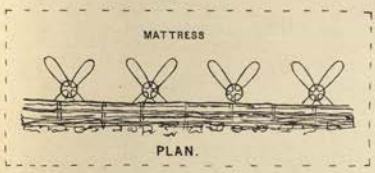
Plate No. [illegible]

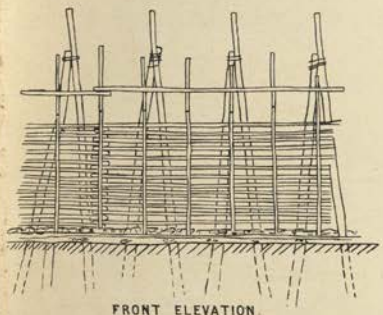
HURDLE OF TWO ROWS OF 4 PILE CLUMPS PLACED CLOSE TOGETHER AND STRENGTHENED WITH LONGITUDINAL STRINGERS.

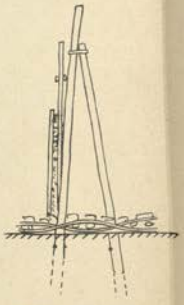




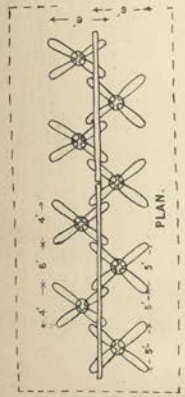
HURDLE OF SINGLE ROW OF 4 PILE CLUMP
WITH WATTLED CURTAIN.

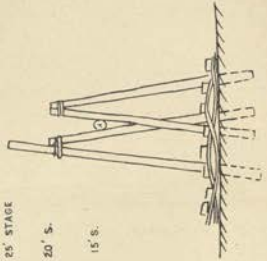


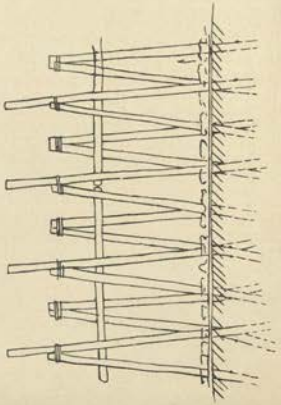




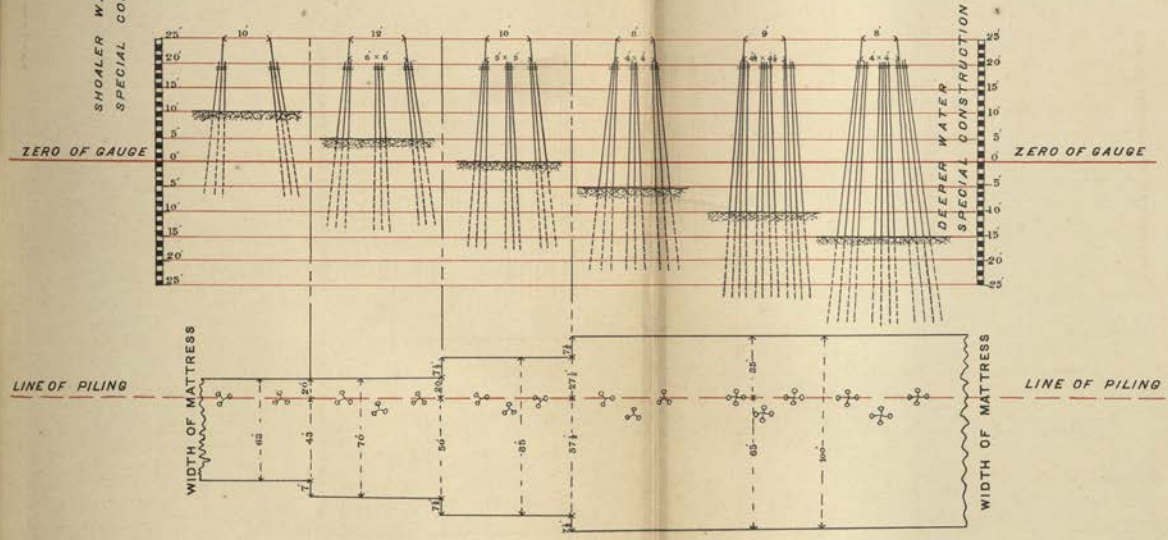
Present Type.
HURDLE OF TWO ROWS OF 4 PILE CLUMPS PLACED CLOSE TOGETHER
AND STRENGTHENED WITH LONGITUDINAL STRINGERS.







TYPES OF HURDLES



LITHO BY THACKER, SPINK & CO., CALCUTTA.

TABLE SHOWING TOTAL COST AND WORK DONE TO DECEMBER 31ST, 1898.

	No. of hurdles.	Prior to July 1st, 1898.				During ½ year ending Dec. 31st, 1898.				Total to Dec. 31st, 1898.			Av. cost per lin. or sq. ft.
		Original length.	Additions in repairs and to maintain.	Square feet of protection.	Amount expended.	Original length.	Additions in repairs and to maintain.	Square feet of protection	Amount expended.	Original length.	Square feet of protection	Amount expended.	
Fort Chartres, e. s. protn., 1893 ...	...	5500	...	730475	47075·85	...	...	...	...	5500	730475	47075·85	8·56 ·06
Crooks, hurdles, 1896	4	3190	...	...	42371·14	..	...	...	...	3190	...	42371·14	13·28
Turkey Isld., dam, '75, 76, 77 ...	...	1834	...	...	25818·10	...	...	...	...	1834	..	25818·10	14·08
Turkey Isld., protn., 1895-96 ...	...	5250	...	911185	35613·31	...	...	...	...	5250	911185	35613·31	6·78 ·04
Ste. Genevieve, Ill. hrdls., 1891, 92, 95, 96, 97, 98, 99.	13	15275	3165	...	314465·37	...	500	...	10886·96	15275	...	325352·33	21·30
Ste. Genevieve, Ill. protn. (More Isld.) 1895.	...	5700	...	1281747	63686·08	...	...	...	...	5700	1281747	63686·08	11·17 ·05
Ste. Genevieve, Mo. hrdls., 1895, 96, 97.	12	18760	...	...	281113·95	...	...	...	...	18760	..	281113·95	14·98
Ste. Genevieve, Mo. protn., 1897, 98, 99.	...	5000	...	983180	48900·44	2350	...	550200	26579·58	7350	1533380	75480·02	10·27 ·05
Kaskaskia, protection, 1878, 79, 81 ...	...	6625	...	...	70040·84	...	...	...	...	6625	...	70040·84	10·57
Kaskaskia Isld., ft. protn., 1899 ...	...	...	...	...	...	5700	...	995800	36246·96	5700	995800	36246·96	6·36 ·04
Chester, Mo. protn , 1897, 98 ...	...	3310	...	637147	33097 53	...	...	...	...	3310	637147	33097·53	10·00 ·05
Liberty Isld , protn. (& dam), '75, 76, 77, 78, 79, 96, 97, 98.	...	15975	...	2609040	176562·99	...	...	...	...	15975	2609040	176562·99	11·05 ·07
Liberty Isld., hurdles, 1896, 97 ...	8	12610	...	...	193927·34	...	...	...	...	12610	...	193927·34	15·38
Hamburg, hurdles, '98, 99 ...	2	4085	...	...	71813·33	...	400	...	13931·89	4085	...	85745·20	20·99
Devils Isld., dike 1, 1875	...	1000	...	...	69446·39	...	...	...	...	1000	...	69446·39	69·45

TABLE SHOWING TOTAL COST AND WORK DONE TO DECEMBER 31ST, 1898.

	No. of hurdles.	Prior to July 1st, 1898.				During ½ year ending Dec. 31st, 1898.				Total to Dec. 31st, 1898.			Av. cost per lin. or sq. ft.
		Original length.	Additions in repairs and to maintain.	Square feet of protection.	Amount expended.	Original length.	Additions in repairs and to maintain.	Square feet of protection.	Amount expended.	Original length.	Square feet of protection.	Amount expended.	
Devils Isld., dams 1 & 2, 1875, 76, 77, 78.		2100	...	...	70156·27	...	...	...	...	2100	...	70156·27	33·40
Devils Isld., protn., 1898, 99 ...	...	7070	...	1144493	49980·10	3100	...	649560	44923·49	10170	1794053	94903·59	9·33
Devils Isld., hurdles, 98, 99 ...	1	1200	...	...	11061·18	600	415	...	23546·16	1800	...	34607·34	·05 19·23
Minton Point, hurdles, 82, 83 ...	6	7715	...	...	35223·98	...	.	...	...	7715	...	35223·98	4·56
Cape Girardeau, prmy. hrdls., 1882 ...	1	3110	...	...	33663·62	...	...	...	...	3110	...	33663·62	10·82
*Cape Girardeau, hrdls., '98, 99 ...	2	2100	...	...	46310 78*	...	...	...	...	2100	...	46310·78	22·05
Burnham Isld., protn., 1899 ...	...	...	...	...	...	3910	..	496550	13593 69	3910	496550	13593·69	3·47
Commerce Isld., hrdls., '98, 99 ...	1	2650	...	...	48855·05	200	...	...	12704·60	2850	...	61559·65	·03 21·60
Powers Island, dam, '97, 98 ...	...	1600	...	...	109681·97	..	...	...	...	1600	...	109681·97	68·55
Goose Isld., hurdles, '99	2	...	...	...	...	3200	...	...	71965·65	3200	...	71965·65	22·49
Buffalo Isld., hurdles, '98, 99 ...	3	3050	...	..	104249·16	2850	188	...	58415·28	5900	...	162664·44	27·57
Beech Ridge, protection 1897, 98, 99...	...	8250	...	1430250	50961·09	1185	...	342990	23733·23	9435	1773240	74694·32	7·92
Cairo, protection†	...	15950	...	...	169274·98	...	602	...	1200·00	15950	...	170474 98	1·04 10 69
Portable Jetties, '95 to 99 ...	...	18705	...	...	82092·42	2710	...	...	20051·79	21415	...	14 ·21	4·77

* Devils Island, hurdles Nos. 9 and 11.

† 1877, 78, 79, 80, 81, 82, 85, 86, 87, 99.

It will be noticed that the totals of cost given by the writer do not correspond with those given by Major Handbury to end of December, but they are allowed to stand as they indicate the proportional distribution of expenditure on the several "items."

Plant and Working Gang.

The plant and working party employed on the construction of a hurdle or hurdles in any one locality on this reach of the Mississippi, from the mouth of the Missouri to the mouth of the Ohio, are about as follows:

Mattress barges and outfit, with 60 men.

Four pile drivers with engineer, master and six men to each.

A steamboat tender with engineer, master and crew of ten

Hurdle gang, including extra men to assist in handling piles, about 25 to 35.

A gang of from 100 to 125, with this plant, would complete about 100 feet length of hurdle per day.

The field cost of the foundation mattress is from $3\frac{1}{2}$ to 4 dollars per 100 square feet, and of the bank mat is from $4\frac{1}{2}$ to $5\frac{1}{2}$ dollars per 100 square feet, in this length of the river.

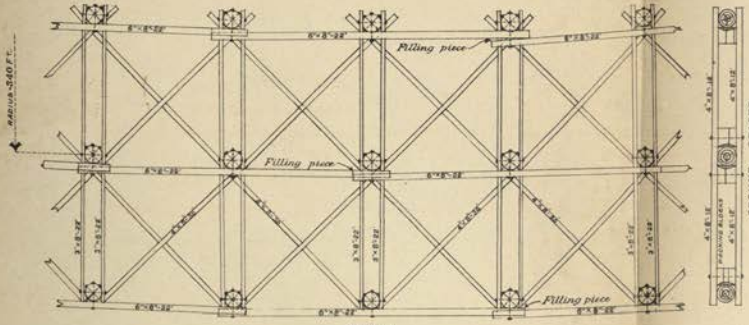
MISSOURI RIVER IMPROVEMENTS.

THE improvements of the Missouri River, on which large sums have been expended during recent years, have comprised clearing of the channel of snags, construction of dikes to narrow and train the channel, and bank revetment. The Missouri is particularly well suited to the use of the hurdle dike as a channel improver, owing to the large amount of sediment carried by its flood water.

The general principles followed in alignment of the dikes, etc., are the same as those applied to the Mississippi River between the Missouri and the Ohio, that is, dikes are built out from the shore nearly at right angles to the general axis of the stream, if anything sloping slightly down the stream, and extended to the line of the projected narrowed channel width. The stream ends of the dikes have been trailed both up and down-stream for a few bents, forming a T, but the general practice now is to trail only down-stream as this is found to give satisfactory results, the end of the dike generally remaining uninjured and the piles quite firm years after they were driven.

The general rule is to keep the tops of the piles about a couple of feet above standard low water, sometimes raising their level towards the shore end up to or slightly above standard high water; though there are instances of dikes having been built with the tops of the piles at the level of standard high water for their whole length. Two such works were constructed in 1898 at Nebraska city. They are, however, curved in plan towards the mid-stream end, and are therefore less liable to collect drift than the ordinary type of dike built at right angles to the stream. Again the leading row of a dike or the head dike of a system is sometimes built at the higher level for the special purpose of sheering or throwing off drift.

The oscillation between high and low stages of the Missouri is much less than that of the Mississippi, and a somewhat shorter pile suffices to obtain a good hold on the bottom than is usual on the latter river. The piles average about 40 to 45 feet in length, and vary in diameter from 12 to 18 inches at the heavy end to 9 to 12 inches at the smaller end. The dikes consist of bents of piles, two, three or four piles in a bent, the piles of each bent being braced together horizontally with squared timbers bolted to them, and also further strengthened with wire cable diagonal braces. The bents are tied together with a top system



PLAN

MISSOURI RIVER COMMISSION

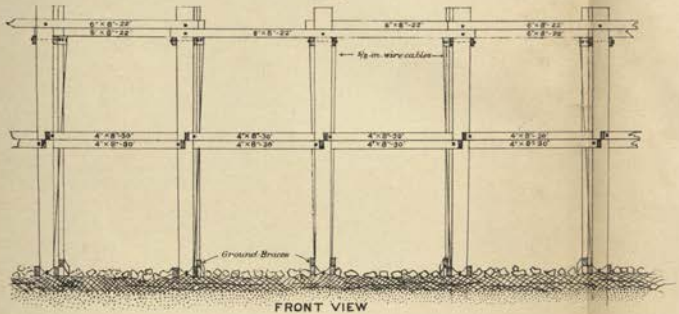
OMAHA DIVISION

Details of Bracing Dike No. 3 Nebraska City Dikes.

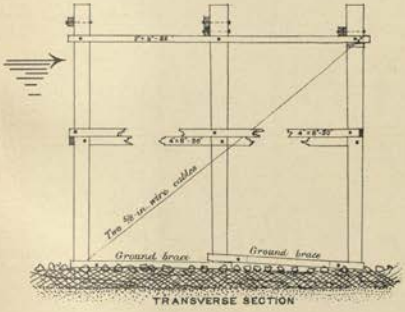
All bolts ⅞ in. diameter

SCALE

0 FT. 12 FT.



FRONT VIEW

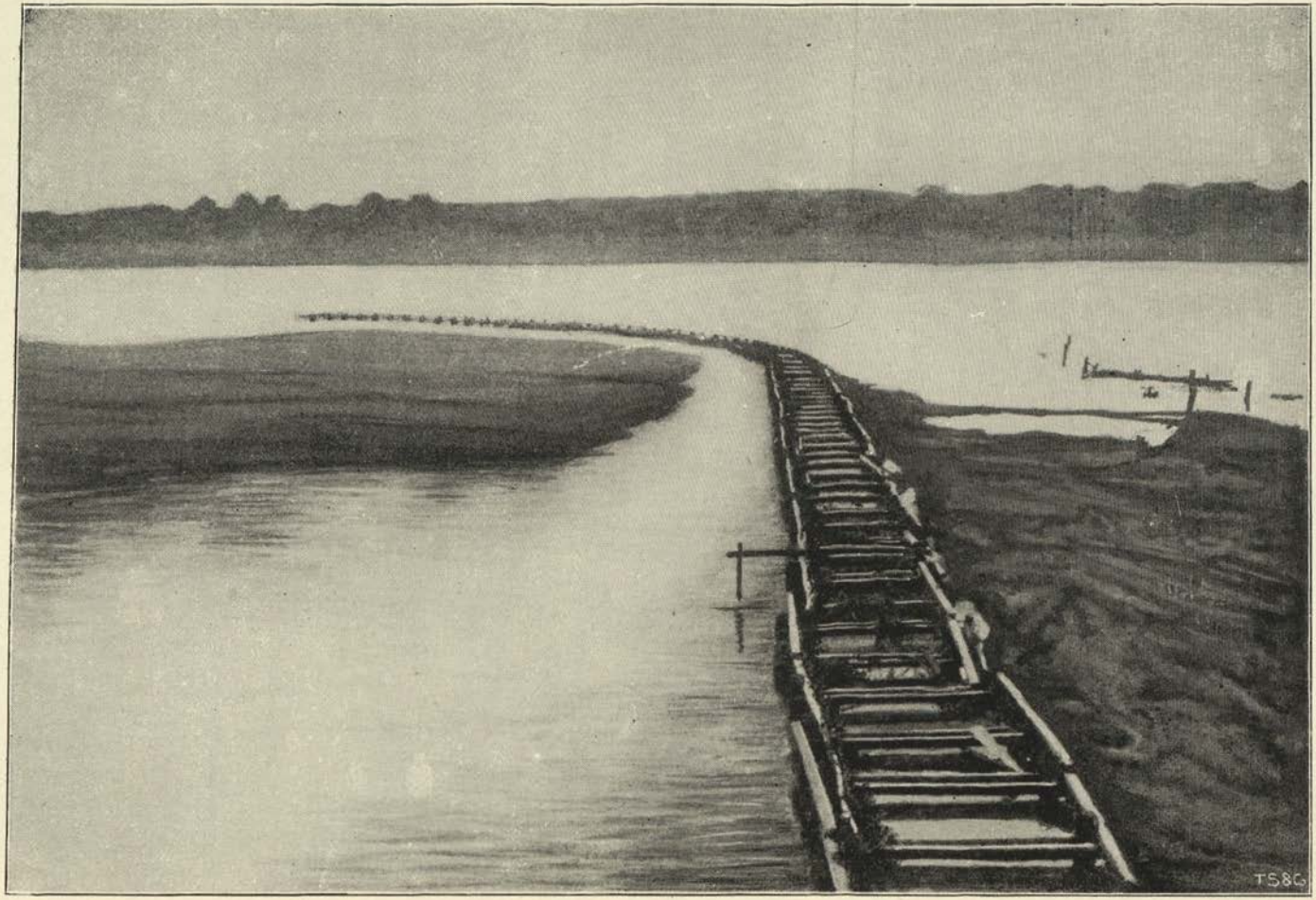


TRANSVERSE SECTION

LITHO BY THACKER, SPINK & CO., CALCUTTA.

NEBRASKA CITY DIKES.

Looking Downstream from above shore end of Dike 3. November 28, 1897, river partly frozen ; stage, about standard low water.



NEBRASKA CITY DIKES.

View from an elevation of 35 feet above top of bank at shore end. June 21, 1898, stage, 2·8 feet below standard high water.

of wales and transverse braces bolted to the heads of the piles, and are sometimes further strengthened by a middle system of diagonal bracing. The wire cable stays are found to be very successful and to add considerable strength to the work.

The plates, opposite, of the curved dikes built at Nebraska illustrate the character of the construction followed on the Missouri River, except as regards the curved ends with which only two have been built. The effect of the dike is shown on the second plate by the accretion below the dike, this being the formation of one season's flow in what was deep water along the side of the river where the channel formerly ran. The object of curving the ends of these dikes was to throw off the heavy drift, to ease the flow around the ends and lessen the eddy there.

The field cost, including foundation mattress, ballasting and all labour and materials in the dikes and shore revetments was $12,200. The work in the two dikes is equivalent to 360 lineal feet of three row dike and 800 lineal feet of two row dike, which gives a through rate of about $10 per foot run. This is, however, stated to be rather a high rate for field cost of dikes on the Missouri. It was due to the shape of the dikes, which added considerably to the difficulty of construction of the foundation mattress, to difficulties in handling material and to want of sufficient barges, etc.

In his inspection of the Missouri River from Jefferson city to Chamois the writer saw many examples of dike construction, revetment, etc. The striking features of an improved length of this river are the enormous accretions between the dikes, which in a few years become overgrown with willows and form new shore lines ; the similarity of the bank line just above and below the heads of the different dikes, where the resulting eddy prevents the deposit of silt ; the middle ground formation ; and, generally, the success attained and the extent of the undertaking which the Missouri Commission control.

The plates at the end of this chapter are of photographs presented by Mr. Waters Fox. Nos. 1, 2, 3 and 4 are excellent illustrations of the use of dikes as channel contraction works, and show very clearly the enormous deposit of silt and drift thrown up behind the dikes in two flood seasons, the period between the photographs being from October 1893 to May 1895

Plates 5, 6, 7 and 8 show the construction and sinking of a woven mattress, and the revetment of a caving bank on the Missouri River.

SILL DAMS.

SILL dams are constructed to maintain the cross section of a channel, to prevent its enlargement by scour, or to reduce its cross-section.

The project for the rectification of the Red and Atchafalaya Rivers provided for several such dams. Two, out of five or six projected, were built in 1883 across the Atchafalaya within two or three miles of its take-off from the Mississippi, with the object of preventing the enlargement of its channel and thus regulating to some extent its discharge as an outlet of the Mississippi at middle and high-water stages.

The writer visited the site of these dams with the Mississippi River Commission on their low water inspection of the river. He learnt that the dams have proved successful and entirely satisfactory in securing the object for which they were built. They are watched and regularly surveyed from year to year to determine whether they need supplementing by other dams above and below, it being originally thought that only two might not suffice for the requirement.

The writer was much interested in these sill dams and, hearing of their success and of the construction of works of very similar description in the partial closing of sloughs and chutes, he put the question to himself: Why can such works not be used with advantage in regulating the flood discharges entering the uncontrolled mouths of some of the Indus canals, for instance the Baghar, or the Gungri in the Delta, or even the Nara or other such uncontrolled canals higher up the river? This question is worth consideration.

Construction of Sill Dams.

The sill was first placed across the river below the low water line. It was built of a single layer of mattresses each 75 feet wide, 300 feet long and 3 feet thick. The mattresses are of willow brush and poles in layers at right angles to each other and held together by timber clamps. They were sunk in succession side by side, across the river, thus forming a sill 300 feet long. That portion of the sill between low water and the crest of the banks was similar to the subaqueous portion, but it was constructed in place and was of a cheaper character. The whole was held securely in position by

Shore of the Atchafalaya near Simmsport, Dec. 1898.

being ballasted with rock, 42 lbs. to the square foot of surface of mat, four times as much as necessary to merely sink the mat to the bottom. The dam was built up of layers of mattresses similar to those on the sill. They were so proportioned as to give the dam, when completed, side slopes of 3 to 1 and width of crown of 30 feet.

Detailed descriptions with sketches of the construction of these and other brush dams will be found in the Chief of Engineer's reports.

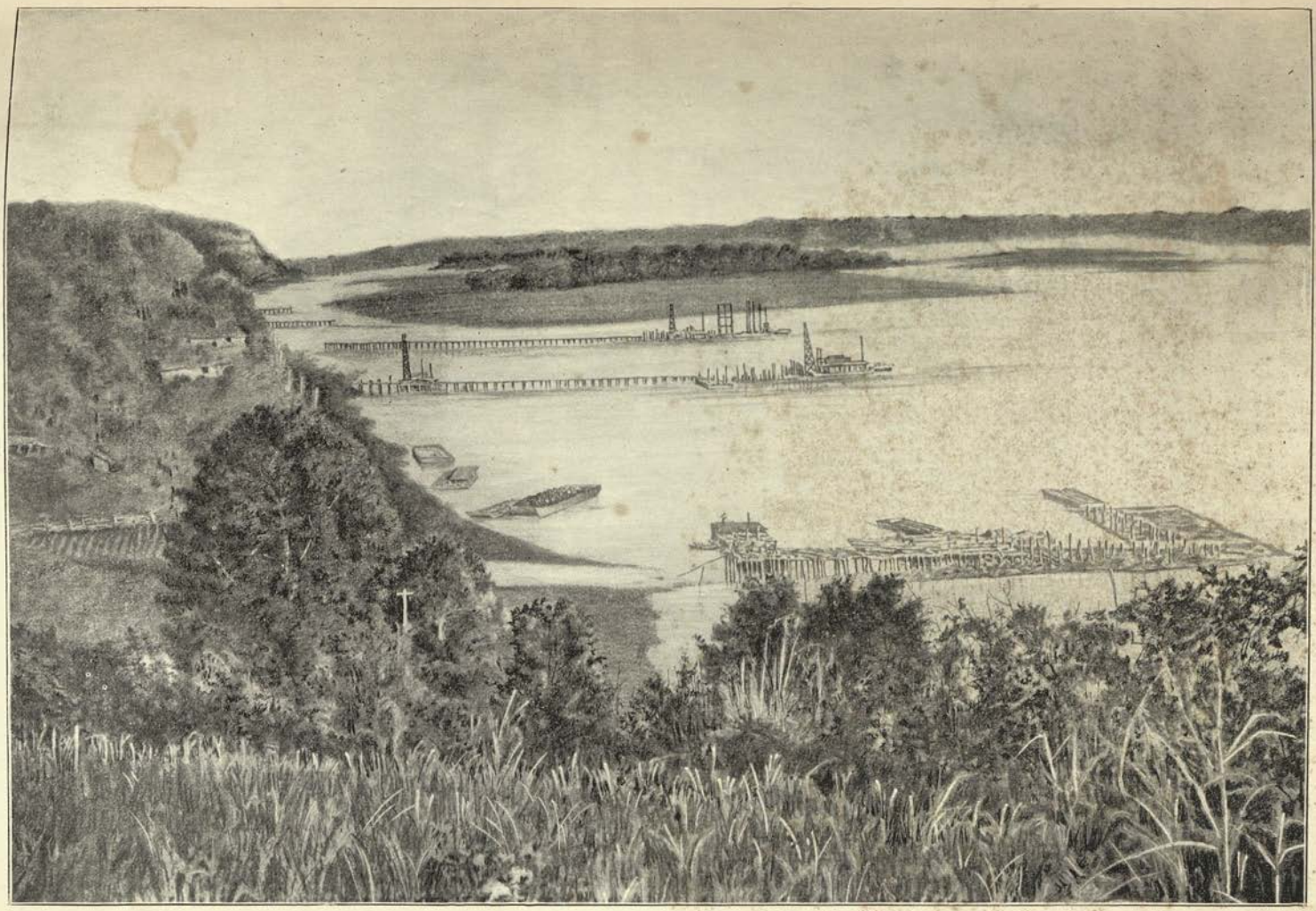


Plate 1.—DIKE WORK.

Bird's-eye View near Bluffton, Mo., showing three permeable Dikes under construction.
View taken October 4, 1893, looking down stream.

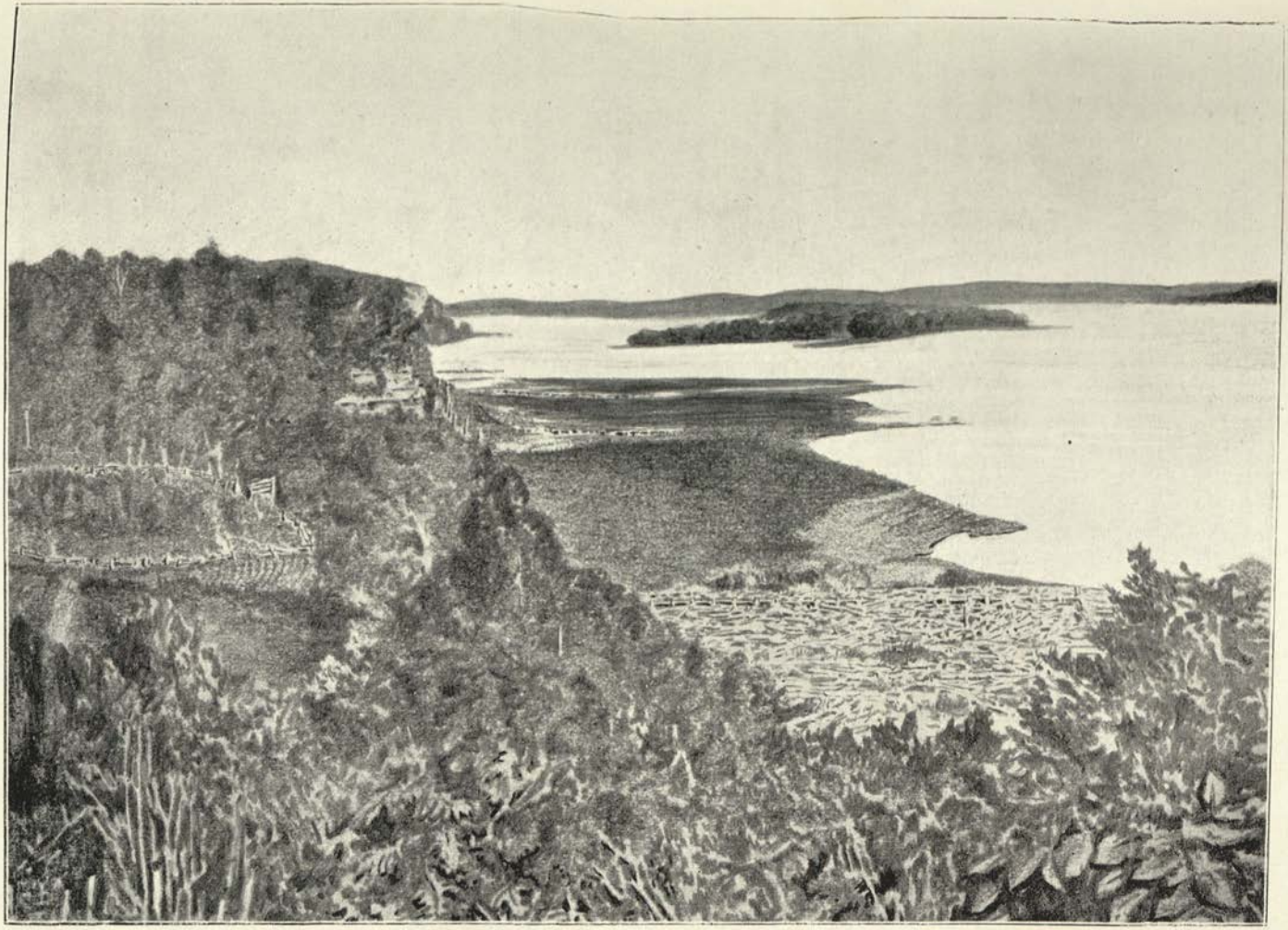


Plate 2.—DIKE WORK.

Bird's-eye View of same Locality as Plate 1, showing accretions formed by Dikes.
View taken May 28, 1895.

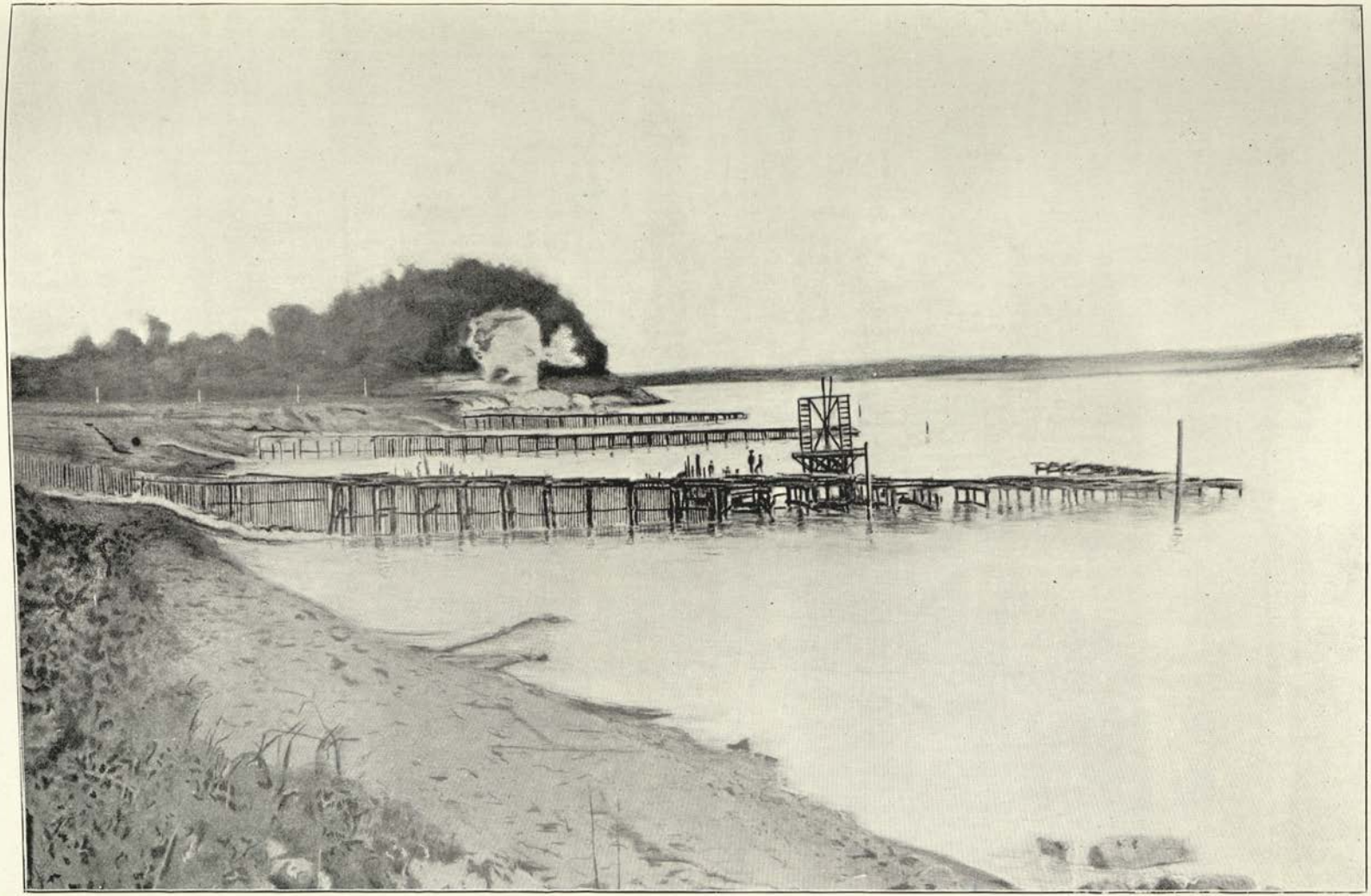


Plate 3.—DIKE WORK.

A system of permeable Dikes in locality of Little Tavern Creek. View taken October 4, 1893, looking down stream.

Plate 4.—DIKE WORK.

View of same Locality as Plate 3, showing accretions formed by Dikes. View taken May 28, 1895.

Plate 5.—REVETMENT WORK.

Showing Construction Party at work weaving Mattress for the protection of the North Bank of St. Aubert's Island. Looking down Stream.

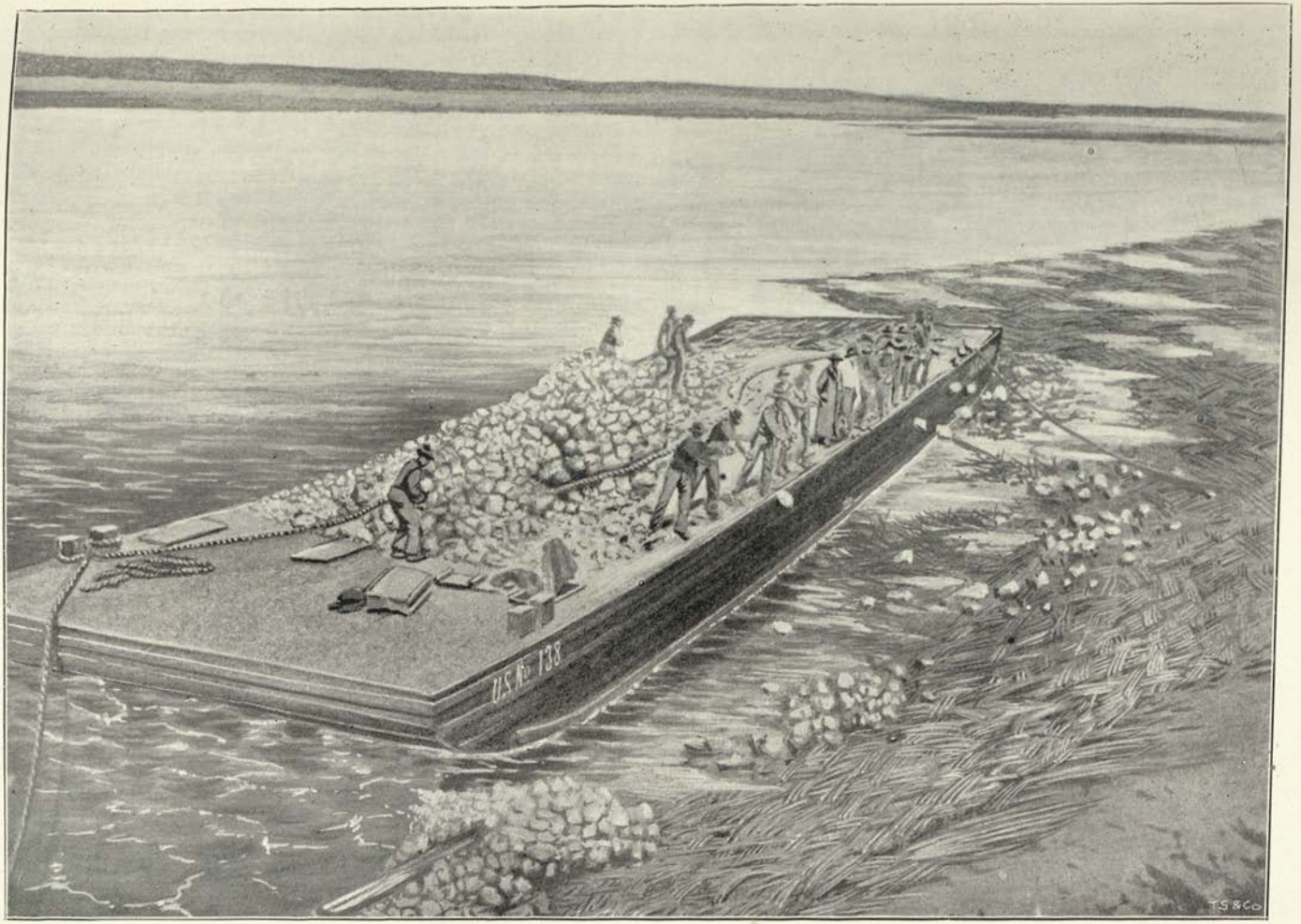


Plate 6.—REVETMENT WORK.
Showing Ballasting Party sinking Mattress. Looking down stream.

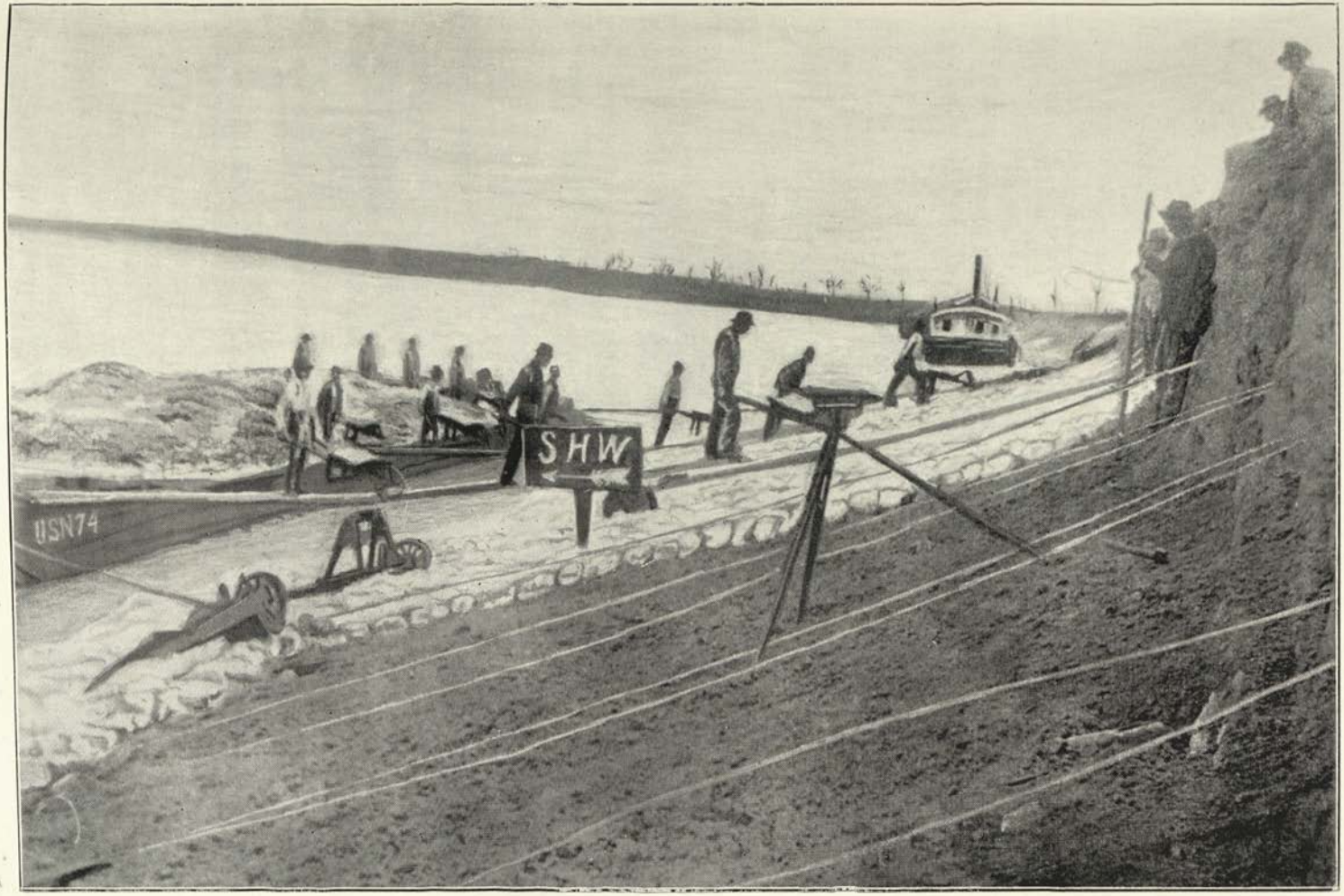


Plate 7.—REVETMENT WORK.

Showing Ballasting Party paving Upper Bank. Top of Paving 2½ feet above Standard High Water.

Revetment Work. View of completed Revetment. Looking up Stream.

CHAPTER VIII.

Subaqueous Rock Excavation—Rock Blasting, Rock Island Rapids—Aetna Dynamite and Blasting by Electricity—Snag Boats.

SUBAQUEOUS ROCK EXCAVATION.

THE only place on the Lower Mississippi where subaqueous rock drilling and blasting has been done is on what is known as the Nonconnah Rock near Memphis. Some 350 odd square feet of rock in the channel there were within 3 to 7 feet of the level of the zero of the Memphis gauge.

The plant employed for its removal to the depth required consisted of a drilling platform, pile driver, mooring barge, two flats, a quarterboat and a steamboat tender.

The drilling platform consisted of a floor or platform on which the drilling machine was placed and worked. It was provided at each end with a 10 × 10-inch spud working in a well and with an overhead truss from which to handle the tools, pipes, etc. It was floated on two pontoons lashed longitudinally to the floor frame. The pile driver was used for hoisting, and its boiler supplied the steam for the drill.

The force employed was composed of a foreman and diver, steam drill engineer, pile driver engineer, blacksmith, cook and ten labourers.

A careful survey of the situation having previously been made, the mooring barge was anchored by wire cables and Chinese anchors 500 feet above the upstream edge of the work. Then with the aid of the pile driver hoisting machine the pile driver, flats and drilling platform were swung into place; the spuds of the platform were then lowered and the platform weight thrown on them by means of ratchets fixed to the spuds and floor of the platform.

Method of operation.

The location of the platform was fixed by instrument from the shore, the area it covered being sounded over every 5 feet and compared with the soundings of the previous survey.

Drilling.

An iron pipe 4-inches in diameter and of length sufficient to project 12-inches above the water surface was stood on the bottom, rammed down through the sand and made fast at its top by lines leading to the floor timbers. This pipe was to prevent the holes to be drilled being filled with sand. The drilling tool $2\frac{1}{2}$-inch in diameter was then placed inside the 4-inch pipe, the drilling machine shipped up over it and connected with the tool and the drilling started. The holes were drilled about $4\frac{1}{2}$ feet deep. After the first hole was drilled the machine was moved over a second 4-inch pipe and drilling proceeded with there. In the meantime the first hole was washed out by an hydraulic jet set inside of the 4-inch pipe, and a cartridge of $4\frac{1}{2}$ lbs. dynamite, with proper exploders and insulated electric wires attached, was pushed into the hole through the 4-inch pipe which was afterwards raised and removed. These operations continued all day, then at its conclusion the platform and pile driver were hauled up near the mooring barge and the loaded holes exploded by an electric battery.

During a working day with one drill at low stage of water nine holes are reported to have been blasted; while with high stage the number was as few as six.

The survey made after completion of the work showed that 30,000 square feet of rock had been disturbed and 2,030 odd cubic yards destroyed. The cost was $4390·00, giving a rate of $1·88 per cubic yard of rock drilled and blasted.

ROCK BLASTING, ROCK ISLAND RAPIDS.

On the upper Mississippi, on the Rock Island Rapids and in their neighbourhood, a good deal of sub-aqueous rock excavation has been done of late years as part of the channel improvement. Bars have been lowered and navigation deepened to four feet at low water in long lengths where formerly there was only one to two feet depth of water.

The rock excavated is a hard white limestone sometimes mixed with conglomerate and, as the water is shallow and the work is on rapids tailing into pools, the conditions are probably as difficult as any to be found in the country. The work of the past ten years may be mentioned as a good example of the successful use of drill boats on rock blasting in shallow water. A quantity of about 14,000 cubic yards of rock was blasted by two boats during the seasons of 1896-97. The cost of blasting and removal was $54,700 or $3·90 per cubic yard. The quantity of dynamite used was 33,000 odd lbs., about 2·4 lbs. per cubic yard.

The writer inspected the plant at Rock Island and gathered much useful information from Captain Townsend, the officer in charge of the district, and from Mr. Gordon, the foreman who has had charge of the blasting operations for several years past, most of which is included in the following notes.

Drill Boats.

A special drill boat, No. 103, was built in 1889 for this work. She is made of pine, fitted with longitudinal hog chains to give stiffness, and is 80 feet long, 22 feet broad, with four feet hold and draft of 22 inches. A small cabin incloses the boiler and part of the machinery. The boat is fitted with four anchorage spuds, one near each corner, worked by means of cranks and rack and pinion gearing.

There are two steam capstans, one near each end, providing means of readily moving the boat either into place or to avoid a blast or passing raft. Five anchor lines are used, one head line and four side lines. In shifting position, the spuds are raised and the side lines used to bring the boat into place.

There are two steam drills running on travellers on one side of the boat, so that the boat hanging by its head lines can be swung across a patch of rock and the drills be made to cover a width of 56 feet on a single range. (See plan opposite for details of the scow and the above arrangements.)

Improvements advisable.

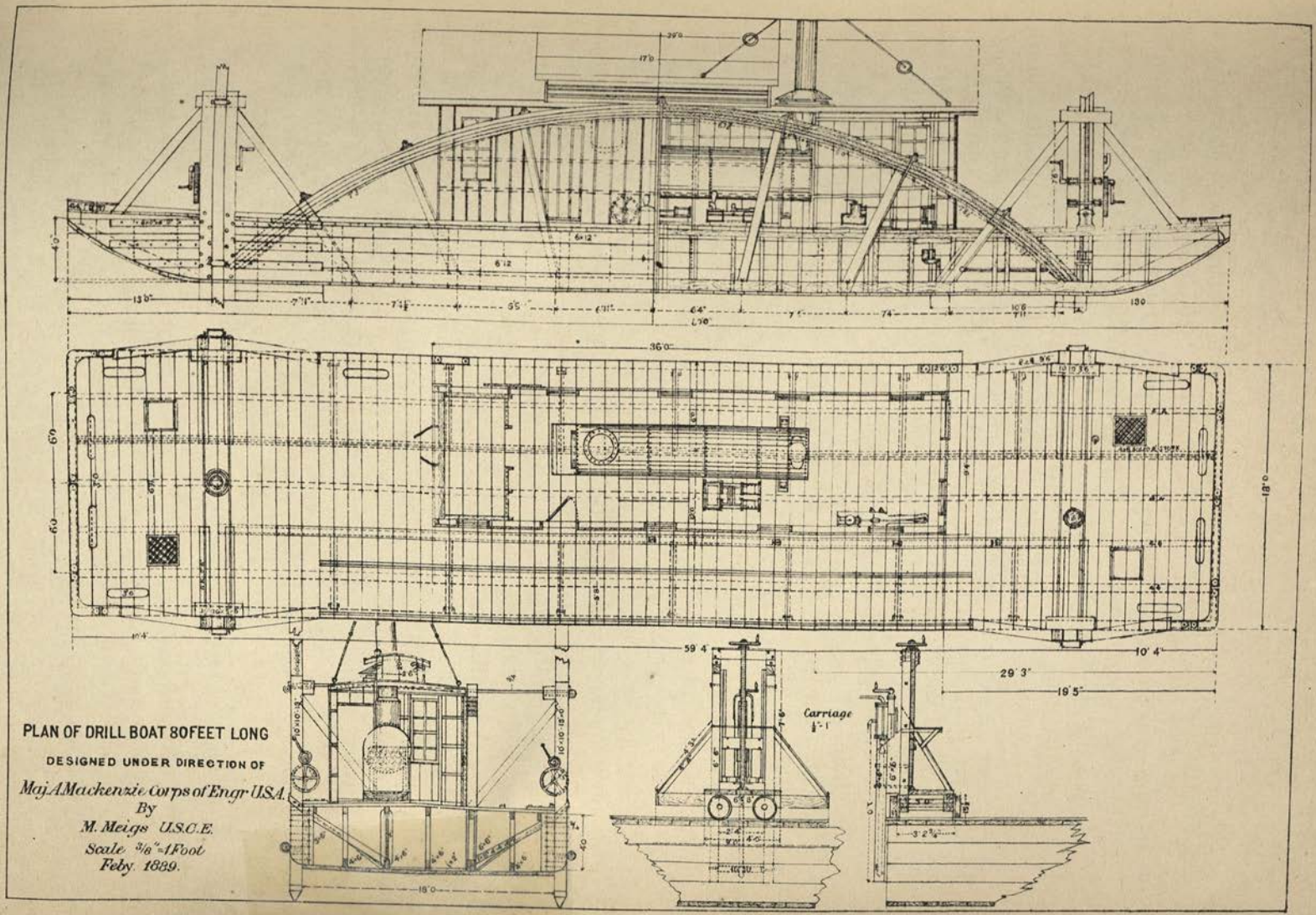
In drill boat No. 6, built some three or four years later than No. 103, the position of the spuds on the drill side of the boat is set back in line with the cabin to allow of the drills having a travel of the full length of the boat. On No. 103 the length of the run is limited to 56 feet, admitting of only thirteen or fourteen holes being bored at 4 feet intervals. On No. 6, which the writer carefully inspected, the length of travel admits of eighteen holes being bored in one line without shifting the boat. Instead of having a rake at the ends, it is better to have a flat or level top to facilitate the movement of the drill carriages and to keep the holes vertical.

Another point worth noting is that a full 2 feet space is advisable between the outside of the cabin and the drill carriage. It is preferable to reduce the inside width of the cabin rather than to limit the outside space on the drill side. This is a fault found with nearly all of the drill boats seen by the writer both in Canada and on the Mississippi. The men generally expressed a wish for a little more room, and as it adds to the buoyancy the extra width may be given with advantage. 80 × 23 or 24 feet is a good size for the boat.

A small compact boiler and a good pump for washing out the holes are necessities. Two small flats for loading holes are found to be a great convenience. They permit of the men working while loading and connecting the wires with greater freedom and nearer the water surface than if these operations were done from the drill boat. A large size battery capable of firing double the usual number of holes is recommended, as a weak battery is a great nuisance.

Cost of Drill Boat.

The first drill boat, No. 103, originally cost about $2,500·00 using however old plant, boiler and drills, etc., in her construction. They have been replaced of late years and her total cost to date is put down at about $5,000·00. Boat No. 6 built later has cost somewhat less. A new boat with new machinery all through, it is said, could be built at the present time for about the same money.



PLAN OF DRILL BOAT 80FEET LONG

DESIGNED UNDER DIRECTION OF

Maj A Mackenzie Corps of Engr U.S.A.

By

M. Meigs U.S.C.E.

Scale 3/8"=1Foot

Feby. 1889.

Drilling Operations.

The distance to which the boat is moved when firing a blast is from 20 to 100 feet according to the amount of explosive used. The latter is considered safe for heavy blasts, though at times stones of from 10 to 30 or 40lbs. weight have been thrown over 200 feet. (These remarks apply to blasting in shallow water. In depths of 14 feet and over the blasts are often fired without moving the boat at all.)

The drill points are star shaped, $3\frac{1}{2}$ inches across, and are made from $1\frac{1}{2}$ inch octagon cast steel. The holes are drilled to a depth of $5\frac{1}{2}$ feet below low water level to obtain a depth of navigation of 4 feet.

The channel to be excavated is marked out with buoys and range poles to facilitate location of the drill boat, and she is kept in correct line with the assistance of other range poles on shore. On being placed in position, and fixed there by throwing her weight on the spuds, drilling is proceeded with, and when a line of holes is completed they are cleaned out with the pump nozzle and loaded. The boat is then moved back and the charges fired by electricity.

A dipper dredge of ordinary pattern works over the blasted area removing the broken rock and noting high points left. Finally, the channel is swept by rails towed along the bottom and if necessary the drill boat is ordered back for a final cleaning up of isolated spots found above datum.

Explosives.

The explosive formerly used was known as New No. 1 dynamite, containing 50% nitro-glycerine and other explosive ingredients, the size of cartridge being 2 inches long by $2\frac{1}{2}$ inches in diameter and weighing about $\frac{1}{2}$lb. each. The charge varied from two to four cartridges according to depth of the hole and the hardness of the rock, one pound being sufficient for a 30-inch hole in soft rock and $1\frac{1}{2}$ to 2lbs. for deeper holes and harder rock.

Then a special powder called "Rackarock" was used for several years and latterly Aetna dynamite. In the top cartridge of each charge is placed an exploder with 8 feet wires serving to connect all the charges with each other and with the battery wires to complete the circuit.

In loading, for convenience in handling the charges, etc., a small flat boat 20 feet long by 6 feet wide is brought alongside. A copper pipe $3\frac{1}{2}$ inches in diameter, having in it a continuous slot about $\frac{1}{2}$ inch in width up one side, is used for guiding the pump nozzle to the

hole and for charging it, the slot being provided to admit of the passage of the exploder wires and removal of the pipe after a hole is loaded.

After the holes have been loaded and the exploder wires connected the drill boat is moved away to a safe distance then, and not until then, the leading wires are connected with the battery, and the blast is fired. If the connecting wires become detached or a misfire occurs from any cause, the boat is swung back, the wires are picked up and examined and, if found intact, the failure is attributed to the exploders, and another round is made up of a single cartridge and exploder for each hole.

General.

Fifty to 60% of dynamite is preferred for hard white limestone. A lower quality is possibly preferable for hot climates, allowing more saw dust or whatever absorbent is used in the manufacture of the explosive. A powerful "exploder" is advised; that in use is known as "The Triple."

The Aetna dynamite is packed in $\frac{1}{2}$-inch pine boxes holding 50lbs. each. 1,000 to 1,500 lbs. is stored at one time on a flat, in a house of inch boarding about $12 \times 7 \times 6\frac{1}{2}$ feet high, the boxes being placed on shelves. The magazine flat is anchored about a quarter of a mile off from the drill boat. The exploders are about $1\frac{1}{2}$ inches long by $\frac{1}{4}$ inch in diameter, fitted with wire, and are packed in small cases. They may be stored nearly anywhere on the drill boat so long as they are kept away from the neighbourhood of the dynamite.

Plant.

The plant used consists of a drill boat, coal barges, two flats for loading, one-quarter boat, one cook and messing boat, one magazine flat and one steam tender.

AETNA DYNAMITE AND BLASTING BY ELECTRICITY.

THE following description of Aetna dynamite, its strength and use, etc., is extracted from a publication issued by the manufacturers, Chicago.

Aetna dynamite is put up in strong paper shells or cartridges, which are packed in pasteboard boxes containing 10lbs. each. Five of these boxes are inclosed in a wooden case which can be conveniently handled and shipped.

Very erroneous ideas are entertained as to the danger of handling, storing and transporting high explosives. The manufacturers claim it is a fact susceptible of the most indisputable proof that Aetna dynamite is much safer in every respect than common powder. It may be thrown from any height and will withstand any shock in handling or transportation, such as the collision of cars, etc. Its explosion is effected by means of a strong blasting cap.

Safety.

Aetna cartridges are 8 inches long, unless otherwise ordered, and a 50lbs. case contains 40 cartridges of 2-inch diameter.

Brands and Grades.

It is divided into grades as follows:

No. 4. 20% nitro-glycerine, suitable for clay, shelly rock, and light work.
No. 3. 27% " " " " " " " " "
No. 2. 40% " " hard work, lead and other ores.
No. 2xx. 50% nitro-glycerine, suitable for hard rock, ores and iron.
No. 1. 60% " " extremely hard rock, ores.
No. 1xx. 70% " " breaking iron and steel and for submarine blasting.

The method in use for exploding Aetna cartridges is by safety fuse inserted in an explosive cap made expressly for the purpose and fired as in ordinary blasting or by means of electricity.

The number of cartridges desirable are fixed for the charge and if the diameter of the holes is too small to permit of the cartridges being easily pushed into them the cartridges may be divided lengthwise or cut into small pieces and rammed into the holes to the required amount. If water is standing

General Directions.

in the holes it is best to preserve the paper of the cartridges and use cartridges of the diameter of the bore hole.

When several cartridges are used, the last placed in the hole should contain an exploder or cap with a fuse attached. When but one cartridge or loose dynamite is used, a piece of cartridge 2 or 3 inches in length with an exploder or cap attached should be pressed firmly on top of the charge. This is called the primer

The amount of dynamite necessary to do good work varies according to the depth and size of the hole and the character of the work, but experience soon teaches the proper charge to be used.

Materials.

Safety fuse is made in lengths of 50 feet neatly coiled and of different grades. Double tape fuse is suitable for wet work. Triple tape fuse can be used with certainty and safety under water.

Great economy in the use of dynamite is assured at all times by using a cap of sufficient strength. The cost of the cap is so small as compared with that of preparing the hole and the dynamite used that none but the very best should be selected.

Blasting under Water.

To remove submerged logs, stumps or piles or wrecks it is desirable, when practicable, to confine the charge in bore holes made by using long handled ship augers. When this cannot be done a pole should be driven into the bed of the stream close to the object to be blasted. Then the desired number of cartridges are tied together and attached to an iron ring after placing a cap with fuse attached or an electric exploder in one of the cartridges. The ring is then slipped over the pole and the charge sinks to the bed of the river. It may be fired by using waterproof fuse or by an electric battery from the shore or a steamboat. For work of this description No. 1 or No. 1xx Aetna should be used. When detached or projecting masses of rock have to be broken up it is sufficient to place the charges upon them, using a larger quantity of explosive than would be necessary if bore holes were employed.

Iron should not be used in tamping or in making a hole in the cartridge for the primer, not that accidents have been known to occur from the use of iron, but because wood answers the purpose equally well and is recognized as being safe. Tamping bars used on drill boat operations are therefore of wood.

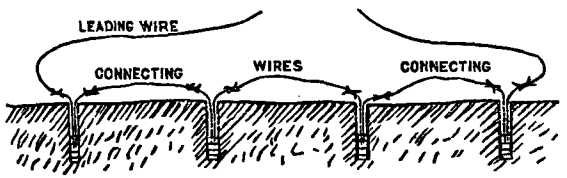
Caps or exploders should be stored and carried apart from the dynamite. If these directions are observed an accident need not be feared.

Freezing and Thawing.

Dynamite freezes at 42 degrees Fahr. and when frozen is either unexplodable or unreliable and must be thawed before using. Serious casualties happen from attempting to thaw dynamite too quickly. This must be done slowly. The best way is to keep the stock on hand in a place that is always at a temperature above 42 degrees; if up to 80 degrees so much the better. The best plan of thawing is to use a thawing kettle made expressly for the purpose with a space for warm water outside and a thawing chamber inside.

Blasting by Electricity.

The use of electricity in shooting blasts either of powder or dynamite commends itself to all who have sufficient work to justify the first outlay for the necessary apparatus: *first*, by reason of its absolute safety; and *secondly*, because the entire and combined strength of the explosive is secured by firing a number of holes at exactly the same instant of time. To blast by electricity one must have a Magneto machine, enough insulated copper leading wire to reach from the machine to the blast, a few feet of connecting wire and a few electrical exploders—one for each hole, with wires a little longer than the depth of the bore hole. The sketch in the margin represents the manner of connecting the holes for firing by electricity. It is called "connecting in series" and is the system commonly adopted.



Directions.

The distance between the holes should be about equal to the depth of the holes. The electrical exploder should be placed in the centre of the explosive or in the top cartridge and its wires should extend about 12 inches above the mouth of the hole if in dry excavation, or if in sub-aqueous about the same distance above the surface of the water. Care is necessary in tamping that the insulation of the wires be not cut or injured. When the holes to be fired at one time are loaded and tamped, the ends of the two wires in each hole should be separated and by the use of

connecting wire one wire of the first hole should be joined with one of the second, the remaining free wire of the second with one of the third, and so on to the last hole, making a continuous connection between the holes and leaving a free wire at each end hole. All connections should be by hooking and twisting together the bare and clean ends. More failures occur from improper connections than from any other cause.

The charges having all been connected the free wire in the first hole should be joined to one of the leading wires, and the free wire of the last hole with the other of the two leading wires extending to the machine. The leading wires should be long enough to reach to a point at a safe distance from the blast.

Everything being ready, and not until all are at a safe distance from the blast, the free ends of the two leading wires should be connected to each of the two set screws on the machine by passing the ends through the holes in the set screws and bringing the thumb nuts firmly down upon the wires.

To fire the blast, if a Smith machine is used, the handle is lifted, then pressed down with increasing acceleration till the rod strikes the bottom of the box. This completes the whole process; the current which has been generated passes through the outside circuit and the blast is fired.

Electrical Exploder.

The Aetna electrical exploder consists of a copper shell about $1\frac{1}{2}$ inches long by $\frac{1}{4}$ inch in diameter, containing the charge of explosives composed mainly of fulminate of mercury. Two copper wires having a cotton covering enter the shell through a plug and are connected at their ends by a very fine platinum wire soldered to them.

The heating of this platinum wire to redness or combustion by the passage of the electric current causes the explosion of the charge. In deep water the wires are sometimes covered with gutta-percha, but this covering is not needed for general work in shallow water.

Electrical Blasting Machines.

Several different types of blasting machines are used; that seen by the writer, a very compact one weighing only 20lbs. odd and occupying less than half a cubic foot of space, known as the Smith Blasting Machine, is recommended. Its price, of capacity for 20 to 40 holes, is $50·00. It is constructed on the Wheatstone and Siemen's principle, having a magnet of the horseshoe character of iron wound with coils of insulated copper wire;

between the poles of the magnet there is fitted to revolve an armature of cylindrical construction carrying in its body other insulated wire coiled longitudinally as to the cylinder.

The rapid revolution of the armature by suitable means generates and sustains in the machine an accumulative current of voltaic electricity of great power which, at the moment of its maximum intensity, is switched off to the outside circuit in which are the exploders, and in the interior of each exploder the ignition is instantly accomplished.

The following simple directions are sufficient for its use: Lift the tooth rod to its full length, then press it down for the first inch of its stroke with moderate speed, but finishing the stroke with full force, bringing the rod to the bottom of the box with a solid thud, and the blast will be made.

Leading Wire.

Leading wire is made in coils of 500 feet. It is usually cotton covered, but gutta-percha covered wire is also furnished.

Connecting Wire.

The connecting wire is a pure copper wire of the same size as the exploder wires, sold in coils of about one pound weight, containing 250 feet length each.

Insulating Tape.

Insulating tape is a useful and convenient article for covering bare wire joints in blasting, either on dry ground or under water. Its composition is Okonite—a superior insulating compound. It makes a waterproof joint and can be applied instantly. The heat of the hand will cause it to stick fast to the bare wire, and it cannot be removed except by cutting it off. It is put up in $\frac{1}{2}$lb. packages in widths of $\frac{1}{2}$ to $\frac{3}{4}$ inches. It costs but a trifle and can be recommended to all blasters for covering bare connections. It is manufactured by the Okonite Company, Limited, 13, Park Row, New York.

Cost of Outfit.

The manufacturers' prices for an outfit suitable for use on drill boat work are as under :—

Smith's Magneto Blasting Machine size No. 4, capacity 20 to 40 holes	$50·00
1 Aetna Reel and Cable	9·00
40lbs. connecting wire at 40c. per lb.	16·00
	$75·00

One lb. in weight or 250 feet length of connecting wire suffices in shallow water for about 25 holes, and 40lbs. for about 1,000 holes.

SNAG BOATS.

THERE is a great variety of snag boats in use on the Mississippi and its tributaries ; few have been built in the river where they are now employed, and there is therefore some difficulty in obtaining descriptions of those one meets. On the lower river, the "Macomb" has been employed for several years past, regularly patrolling and removing snags, wrecks, etc., according to requirements. The "Wright" is also employed on the main river. Both of these boats might be called mammoth machines as they are capable of handling snags of practically any size and weight, and an instance is mentioned of a locomotive having been lifted bodily out of the river without any great difficulty. On the Missouri, the "Suter," another large and very efficient machine, has been employed for some time. The cost of these boats approximated $100,000 each, rather above the figure Government are prepared to spend on the Indus River on a snag boat, and descriptions of them may therefore be omitted.

The "Reece" has a steel hull and cost about $60,000. Working down to smaller boats suitable for removal of light snags in shallow water, the Wichita has been specially recommended.

Snag Boat Wichita.

The Wichita was built in 1881, being designed specially for use on the Arkansas. She is 125 feet long, 26 feet wide with 3 feet depth of hold and draws 15 inches of water. Her accommodation is sufficient for a crew of 25 officers and men with their outfit and supplies.

The boat is propelled by two engines, $8\frac{1}{2}$ inches diameter cylinder and 3 feet stroke, supplied with steam from two boilers 36 inches in diameter and 16 feet long, with four lap-welded flues in each, two 8 inches and two 10 inches in diameter. The hoisting power is supplied by a steam capstan, with double reversible engine 6 inches by 12 inches. The spindle is steel, 5 inches diameter. The power is applied through a crane capable of lifting between 40 and 50 tons. The outfit of rope, tackle, saws, axes, &c., is complete.

Snag Boat.

This boat is reported well adapted to her work. She is stated to have cost about $12,000. A view of her is given opposite.

Wabash River Snag Boats.

Small snag boats for the Wabash were built in 1880 which cost about $7,000 each, including all appliances ready for work. They are reported to have removed snags up to 30 tons in weight.

The hulls are of pine, 120 feet long by 24 feet wide and 4½ feet deep. They have two longitudinal and three cross bulkheads for the double purpose of stiffening them and preventing them sinking when punctured by snags. The draft of water when coaled is 22 inches, and they have a speed in still water of about 8½ miles an hour.

The power capstan is driven by an engine having 6-inch cylinders and 12-inch stroke, geared to give 27 turns of the main shaft to one of the capstan. The power may still be further multiplied by blocks and falls which depend from shears on the bow. The boilers are each 22 feet long, 36 inches in diameter, and furnish steam for both the propelling and hoisting engines. The cabins are plain and suitable for the accommodation of working men.

These boats are easily handled, not expensive to work, and can run in very little water. Their bottoms are strengthened by longitudinal oak planking and plating of iron.

Twin Bow.

Mention may be made of the Suter as an example of the larger boat which is provided with what is known as a twin bow or "boot-jack" pattern hull. An adjustable chain is provided across the bow which, when about to attack a snag, is lowered on the bottom, the boat is run forward and picks up the snag which is then lifted to the surface and landed on a cross beam, after which the snag can be sawn into pieces and removed with great facility. This twin bow arrangement seems very advisable on any efficient snag boat for heavy work. It is not provided on most of the smaller snag boats built in former years.

The length of the Suter is 189 feet over all, with breadth amidships of 77 feet. The engines are compound oscillating and condensing. The high pressure cylinder is 20 inches in diameter, and low pressure 32, with a stroke of 4 feet. Boilers are 42 inches in diameter, and have four flues, each 9½ inches in diameter. The cost of operating her is about $4,000 per month.

CHAPTER IX.

Dredgers and Dredging—Hydraulic Piles—Dredge capacity tests made in 1898—General remarks and comparison of Dredges—Preliminary Specification for large Dredge Indus—Self-propelling Dredgers—Small Dredge Indus.

DREDGERS AND DREDGING.

THE writer approaches this subject with some diffidence. It has indeed been one of the most difficult the Mississippi River Commission have had to consider, and of late years it has been a subject of special study and experiment. It must however be borne in mind that the object of these notes is to record information that may prove useful to Engineers in India in the conditions there prevailing; that an attempt is not made to give a complete history of the work on the Mississippi, but rather to note merely on such of the practice of Mississippi Engineers as may be helpful to the Indian Engineers, particularly of the Indus River.

If the Mississippi Commission had commenced their research in this direction a few years earlier than they did, it is quite possible that they would have designed by this time an approved pattern of machine to fit particular conditions but, as their experiments have only covered a few years, evolution is still going on and, though very satisfactory results have been attained in certain directions, there are still several features of importance on these enormous dredges (of capacity of from 1,000 to 2,000 cubic yards per hour) which may be considerably modified or changed before it can be said that the dredge finally adopted is the very best obtainable for the requirements.

Mr. Ockerson on this subject.

The end may, however, be said to be in sight, most successful results having been obtained, and a study of the progress made in the last few years will well repay the time given to it. Fortunately, Mr. Ockerson, member of the Mississippi River Commission and formerly Assistant Engineer in the Secretary's office, has written a clear and concise history of the development of "Dredges and Dredging on the Mississippi River," and the writer proposes, as the best manner of studying this subject, to condense and extract such descriptions as will help to bring our knowledge of the Mississippi dredge up to the present time.

CAPACITY TEST, U. S. DREDGE "EPSILON," March 14, 1898.
Arrangement of Dredge, Floating Pipe, Measuring Barge and Pile-sinkers.

For the purpose of his paper, Mr. Ockerson divides the Mississippi River into four lengths or sections, *viz.* : (1) That portion extending from the Falls of St. Anthony to the mouth of the Missouri, 712 miles; (2) from the mouth of the Missouri to the head of the alluvial basin, practically to the mouth of the Ohio, 210 miles; (3) from the Ohio to the mouth of the Red River, a distance of 750 miles; and (4) from the Red River to the Gulf, a distance of 310 miles.

The particular characteristics of the several lengths mentioned will have been gathered from previous notes, but it may be well to briefly mention them again. In the first length the water carries but little sediment; bank erosion is slight; navigation is usually suspended during the winter; the low water slope averages about 0·5 per mile; the low water discharge is about 25,000 cubic feet per second, and the high water about 350,000 cubic feet per second.

The second reach is the first to take up the enormous load of sediment brought down by the Missouri; here permeable dikes are at their best, as immense deposits are easily induced; the banks are somewhat higher than in the reach above; the extreme oscillation between high and low water is about 36 feet; the low water slope averages 0·6 per mile; the discharge varies from 45,000 to 850,000 cubic feet per second; low water on the bars, until lately, gave a depth of navigation as little as 4 feet; overflows are infrequent, as a conjunction of the floods of the Upper Mississippi and Missouri is uncommon; sand bars are numerous and crossings frequent.

The third reach is through deposits which have been built up and torn down repeatedly; in places it is exceedingly crooked, as near Greenville; the caving reaches enormous proportions, especially at about the middle third of the reach; the oscillation between the high and low stages reaches 53 feet odd; banks are high; overflows are frequent; bars which obstruct low water navigation are not very numerous and the depth rarely falls below 5 feet on them, while the greater part of the river has water of ample depth to satisfy demands of navigation; low water conditions which interfere with navigation rarely exceed four months in duration; the low water slope averages about 0·35 feet per mile; floods usually occur in February or March and low water in September to December; some of the bends have depths of over 100 feet; and the discharge varies from 65,000 to nearly 2,000,000 cubic feet per second.

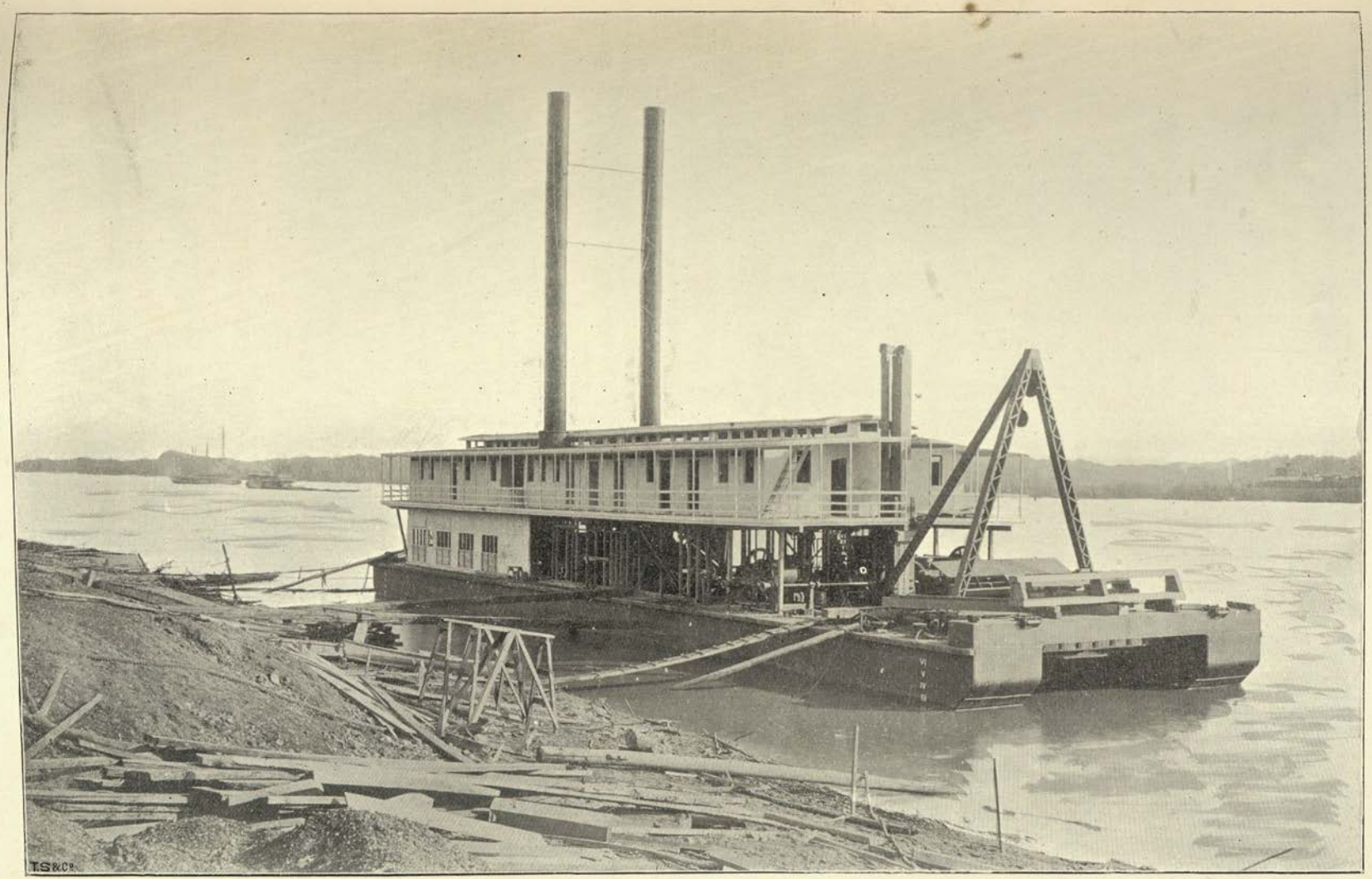
In the fourth reach the channel is narrow and deep, the banks are tolerably stable and sandbars as obstructions to navigation are almost unknown; the oscillation between high and low water at the upper end is 50 feet odd, but it tapers down to nothing at the Gulf; destructive floods invariably come from the Ohio, augmented at times by the tributaries below its mouth.

"The characteristics of the reaches described are pronounced, and they differ so widely as to make the improvement of each a problem by itself. The last named reach should perhaps have terminated at the head of the Passes instead of at the Gulf, 12 miles farther down. Where the current of the river meets the slack water of the Gulf of Mexico bars are formed which require special treatment."

Sand Bars as obstructions to navigation.

Ridges of sand are found on what steamboat men call crossings; that is on the channel followed by boats when crossing from a pool lying in a bend along one bank to the pool in the bend of the opposite bank below. "These bars may be piled up to such an extent that during a high or even medium stage their crests may be several feet higher than the surface of the water at low stage. The thread of the channel at high stages does not follow the low stage channel, but crosses and re-crosses it."

The problem for consideration on the Mississippi is the opening of channels between successive pools. Whatever is done in this way is merely temporary, answering for one low water season only, as the next flood probably changes the thread of flow to such an extent as to cross the open channel and obliterate it. "So far the problem seems simple enough. The only thing necessary is to cut through the reef composed principally of loose sand; but there are other difficulties familiar only to the engineer who has been taught by long observation and experience. While this artificial cutting is going on, nature is doing some cutting on her own account, but on such a gigantic scale that the work of the largest centrifugal pumps seems insignificant. By the time the engineer gets what he considers a dredge of enormous capacity into position to open a cut ..... nature perhaps changes her mind and opens a channel of her own; ..... or what would be worse, throws such a volume of deposit over the bar that the dredge cut is filled as fast as the material can be removed. It is this tremendous volume of material that is moved along the bottom by the current, complicated by unforeseen subtle changes in



U. S. Dredge Gamma. General View, afloat. Dec. 31, 1896.

direction and force of flow, that often mocks the best efforts of the engineer."

Mr. Ockerson gives a history of the different devices which have been tried in former years for the improvement of the channels of the river. He divides them into four general classes, *viz.*, Stirring and Scraping, Current Deflectors, Jets, and the Suction Dredge. A perusal of his description leads to the conclusion that few of these devices were of any practical use in improving navigation, with the exception of water jets and auxiliary devices, and they were inadequate for the requirements.

Appointment of a Committee to study and report on a project for dredging.

Then in November 1891 the Mississippi Commission, in response to a representation from the steamboat transportation lines below St. Louis, appointed a Committee of two "to study the subject of the construction and operation of such appliances for dredging as can be applied to the deepening of the Mississippi River over the bars in extreme low water," .....and "prepare and report a project for the construction of a dredging boat of as large capacity as can be handled in the channel of the Mississippi River at low water with safety and convenience."

It was represented that if the relief for low water navigation depended upon the completion of the permanent improvement work, by the time it came there would be no traffic. The Commission up to this time were operating under a law which required them to prepare a plan to permanently locate and deepen the channel, and had omitted temporary expedients from their operations, but they were beginning to realize, as has been stated elsewhere, that the permanent improvement of the channel by continuous bank revetment would require a number of years for completion and that the practicability of the work would involve a very heavy expenditure and probably special cultivation of willows and, as a supplement to their continuous bank revetment work, they were therefore prepared to undertake the investigation of the use of dredges on temporary improvements across bars.

Colonel Suter and Mr. Henry Flad were appointed as a committee on this question. After a thorough investigation of the matter, they concluded that among the various devices for temporary relief dredging was the only means which held out a reasonable promise of success, and they recommended the construction of an experimental dredge.

Experimental Dredge Alpha.

This experimental dredge was equipped with an Edwards centrifugal pump, having a curved drag-suction, at one end and an Allis-Reynolds screw pump, having a straight suction with jet agitators, at the other end; the object being to make practical tests of the efficiency of the different devices. The pumps, engines and boilers were designed by their respective manufacturers.

"The Edwards pump runner was 6 feet 4 inches in diameter and was operated by a compound non-condensing vertical engine, with cylinders 15 and 27 inches in diameter, respectively, and with 20-inch stroke. The suction and discharge were each 30 inches in diameter. The Allis-Reynolds pump was operated by a compound non-condensing vertical engine with cylinders 8 and 16 inches in diameter and with 12-inch stroke. The suction and discharge pipes were each 30 inches in diameter. The jet pump was of the Allis-Reynolds pattern with suction and discharge 15 inches in diameter. This pump operated six jets 2½ inches in diameter under a head of about 20 feet. By this means the material was loosened and divided up so as to enter the suction of the sand pump thoroughly mixed with water.

"The steam for the various pumps, etc., was supplied from four boilers, 38 inches in diameter and 28 feet long, of the type in common use on the Mississipp River steamers. Hoisting apparatus was also provided for raising and lowering the suction and moving the dredge.

"The above-described machinery was mounted on a wooden hull 130 feet long, 36 feet wide and 8 feet in depth. The dredge, in working order, drew about 4 feet of water.

"The material pumped was discharged through a floating pipe-line made up of sections of pipe 33 feet long connected by means of strong rubber joints and iron coupling bars. An air chamber on each side of the discharge pipe served to float it when loaded with 10% or less of sand.

"The experimental dredge was erected under the immediate supervision of Mr. Flad in the Fall of 1893. Tests were begun in November and continued throughout the Winter and the following Spring. As a result of these tests the Allis-Reynolds pump at the bow of the boat was found deficient in engine power, and the drag suction at the stern of the boat could not be manipulated so as to give a regular and satisfactory supply of material. The Edwards pump gave good results, and the jet agitator suction head was found to be satisfactory. The jet pump required extensive alterations before the required results could be secured.

"The buoyancy of the floating pipe-line was too small, and great care was required to prevent sinking the pipes by getting an overload of sand in them.

"Another unexpected difficulty developed in the use of these pipes. When swinging freely in the current, with the lower end open, and the pump running,

the pipes would kink up at the joints. After experimenting with jets, discharging in air and water, the conclusion was reached that the kinking was due to the centrifugal force of the flowing water acting at the flexible joints of the pipe. That is to say, when the pipe swings freely in the current, it is never straight, and any bend met with by the water flowing in the pipes at a high velocity is naturally exaggerated. This difficulty was fully overcome by attaching a baffle plate to the last section, a short distance from the end of the pipe to receive the impact of the discharge. By shifting this baffle plate so that the discharge strikes it at an angle, the pipe-line can be deflected to the right or left.

"The experiments had solved many of the difficulties; the Allis-Reynolds pump and the drag-suction were discarded, the Edwards pump was shifted and attached to the jet suction, and subsequently a cabin was built for the accommodation of the crew. This dredge, the Alpha, was ready for use on removal of sandbars on the lower Mississippi River during the low-water season of 1895."

The tests made during these experiments included the determination of the capacity of the dredge. A measuring barge was fitted up with suitable valves to be attached to the lower end of the discharge pipe where the discharge could be deflected into the barge for a known interval of time when the running conditions were about normal. A special barge was built for this purpose, stiffened with trusses, with special floor, tight bulkheads, gate valves, bins, etc., all of which, with the method of making the test, are described by Mr. Ockerson, and need not at present be followed out here.

A new pump similar to that on the Delta, with a 66-inch runner, 33 inches wide, was put in the Alpha in 1897.

The "Beta" was the next dredge constructed.

Dredge Beta.

"This dredge (built by Mr. Linden Bates, of Chicago) has two independent dredging machines complete from suction to end of discharge pipes. The sand pumps are of the centrifugal pattern with runners 7 feet in diameter and with 8 arms in each runner. The suction for each pump is 33¾ inches in diameter, and is split near the pump so that the water enters the casing from both sides. The discharge for each pump is from a single 33-inch pipe leaving the pump chamber from the top. The suction for each pump divides near the forward end of the hull into three suctions, each 19½ inches in diameter. A cast-iron elbow is riveted to the hull at the bow for each of the three branches, which are provided with elbows of hammered copper ⅜ inch thick, and these work in the iron elbows and form a radial, telescopic joint. The axis of rotation is the centre of a 7-inch shaft supported on brackets at the bow of the boat. The elbows are concentric with this shaft. These three suctions are framed together and can be raised or lowered, as one piece, through a depth of 20 feet.

"Each of these suctions is provided with a vertical revolving cutter, 5 feet in diameter and 5 feet long, with 12 nickel-steel blades on each cutter. These serve

to loosen up the material so that it will readily enter the suction. They are spaced 6 feet apart from centre to centre. There are six of these revolving cutters for the two pumps. They are driven, through a system of spur gearing, by a cross-compound non-condensing engine with 14½ and 29-inch cylinders and an 18-inch stroke. The engines make about eight revolutions to one revolution of the cutters. The cylinders are some 20 feet apart and are connected by a 5-inch pipe.

"To support a portion of the weight of the cutter machinery, a pontoon is provided for each set of suctions. This pontoon is made of steel plates, and is built around the various pipes and frames. Each pontoon has a displacement of 1,000 cubic feet.

"The sand pump shaft is of forged steel, 10 inches in diameter, and 12 inches in diameter where it passes through the pump runner. Stuffing-boxes are provided where the shaft passes through the pump casing. Each pump is operated by a direct-connected, triple expansion, vertical, inverted, four-cylinder, tandem engine, provided with jet condensers. The cylinders are 20½, 33, 38 and 38 inches in diameter, respectively, and the stroke is 24 inches with the cranks set at 180 degrees. These engines are run at a speed of about 130 revolutions per minute, the indicated horse-power of each being about 1,250, with boiler pressure of 175lbs. Each engine is provided with a Worthington duplex air pump and jet condenser, with cylinders 14 and 19-inch and 15-inch stroke. They are also arranged to exhaust without condensing. The steam is supplied by four Heine boilers so arranged that they can be used together or independently, as may be desired. Each boiler has two shells 36 inches in diameter and 18½ feet long. The water legs are connected by 171 tubes, 3½ inches in diameter, and 15¾ feet long. There is one smokestack to each pair of boilers, each stack being 64 inches in diameter and 57 feet high above the breaching, or 73 feet above the water-line. The main steam pipe between the boilers and engines is 12 inches in diameter. The usual steam gauges, blow-off valves, &c., are provided.

"The water-supply for the boilers and journal bearings is filtered by means of two filters, each 11 feet long and 6 feet in diameter. The filter bed is supported on a perforated cast-iron bed fixed near the bottom of each filter. There are three layers of brass wirecloth with 10, 60 and 10 meshes per inch, respectively. These support a bed of crushed quartz made up of layers of different degrees of fineness and about 2 feet thick. The sediment which gathers on the filter bed is stirred up by two sets of arms which can be revolved by means of gearing, and the clear water from one filter is used to wash the other. The filters are supplied by a duplex pump with 8-inch suction and 7-inch discharge, and the water is carried through an alum coagulent to the tops of the filters under a pressure of about 60lbs. The filtered water is drawn from the bottom of the filters by the boiler feed pumps, and passes through a vertical pressure heater provided with one hundred 2-inch corrugated copper tubes 73¾ inches long The exhaust steam from the cutter, the winding engines and the pumps passes through this heater.

"The winding engines are placed near the bow of the boat. There are six drums operated by a double-cylinder, link-motion, reversing engine with 12¼-inch cylinders and 15-inch stroke. Four of the drums are 24 inches in diameter and 40 inches long. Two of these drums are used for side warping, and are geared 25 to 1. The other two are used for pulling the dredge ahead, and are geared 30 to 1; 1,200 feet of ⅞-inch wire rope is used for this purpose. The two end drums are 30 inches in diameter and 28 inches long. They are used for raising and lowering the suctions.

"At the stern of the boat is a steam capstan and a spud hoist. There are two vertical anchor-spuds and one push-spud at the stern of the boat. The anchor-spuds are of oak, 24 inches square and 40 feet long. These were intended mainly as pivots on which to swing the boat, so that a wide cut could be made by moving the suction on the arc of a circle. This method is not well adapted to streams with a strong current. These spuds and the push-spud are raised or lowered by means of a 3-drum friction hoist moved by a double 8×10-inch engine. The push-spud is an iron beam 28 feet long, with a steel shoe at the lower end. The inner end of the beam is attached to the piston rod of a hydraulic cylinder 7 feet long and 15 inches in diameter. The piston rod passes through the hull plating in a stuffing-box. This spud has never been used.

"The machinery is mounted on a steel hull 172 feet long and 40 feet wide. It is 7 feet 2 inches deep in the waist, and for 36 feet from the forward end and 16 feet from the after end it is 10 feet 10 inches deep. These deep portions are decked over, as are also the guards, for the entire length. The plating on the sides of the hull is ⅜-inch thick; the other plating outside is $\frac{5}{16}$-inch thick. The bow is double-plated on the head and rake. The cross floors, spaced 2 feet between centres, are 12 inches I-beams, weighing 32lbs. to the foot. On these, at intervals of 3½ feet, are longitudinal stringers of the same form and height, weighing 40lbs. to the foot. These floor frames are decked over with ¼-inch plating and extend to within 6 feet of the bow. The space between this plating and the bottom is divided into ten water-tight compartments. The hull is further divided into seven water-tight compartments above the water bottom by means of five cross bulkheads and one short longitudinal bulkhead.

"The bases of the pumps, engines and the boilers are set on the water bottom. Two coal bunkers are provided, with a capacity of about 30 tons each. The dredge is fitted with a travelling crane of ample capacity to handle all parts of the machinery.

"No quarters are provided for the crew of this dredge. The cabin is only sufficient to protect the machinery. The boat is equipped with an electric light plant and a full complement of shop tools, such as lathe, drill press, etc."

The requirements of the contract fixed the limit of draft at 4½ feet and the width at 40 feet. When the dredge was completed, the draft was found to be about 6½ feet.

"The weights of the various parts are about as follows: Hull, 633,340lbs.; main engines and pumps, 183,576lbs.; boilers, 405,880lbs.; cutter engine,

27,460lbs. ; forward hoist, 51,500lbs. ; spud hoist, 20,450lbs. ; ladders, 56,800lbs. The total displacement when running, with suction and discharge pipes, boilers, filters, heaters, etc., full of water, and a supply of coal on board, is about 1,175 tons.

"The discharge consists of two independent pipe lines, each 1,000 feet long. A deflecting baffle plate is provided for the end of each line. Eight of the sections of each line are 100 feet long, and four sections are 50 feet long. When the pipes are empty, the pontoons draw about 14 inches of water. The pontoons are made of $\frac{3}{16}$-inch tank steel, and are fitted with water-tight bulkheads about 16 feet apart. In section they are the shape of a semi-cylinder, with an outer radius of $30\frac{3}{4}$ inches and an inner radius of $16\frac{3}{4}$ inches. The discharge pipe lies in the float thus formed and is made of $\frac{1}{4}$-inch steel. The different lengths are coupled about as described in connection with the Alpha.

"Quite a number of defects were developed in the use of this dredge, many of which were remedied. At first the cutters all worked in the same direction, and the result was that the dredge was pulled sidewise out of the cut. This was remedied by changing one set of cutters to work in the opposite direction. The breaks in the gearing of the cutter machinery were frequent, although the spur gears were made of nickel steel, and the pinions of phosphor bronze. The 6-drum hoist also gave considerable trouble. The cutters were found to be very much longer than necessary, and their operation drew heavily on the boiler capacity. The unexpected draft developed difficulties in coaling, and in manœuvring the dredge over the shoal bars."

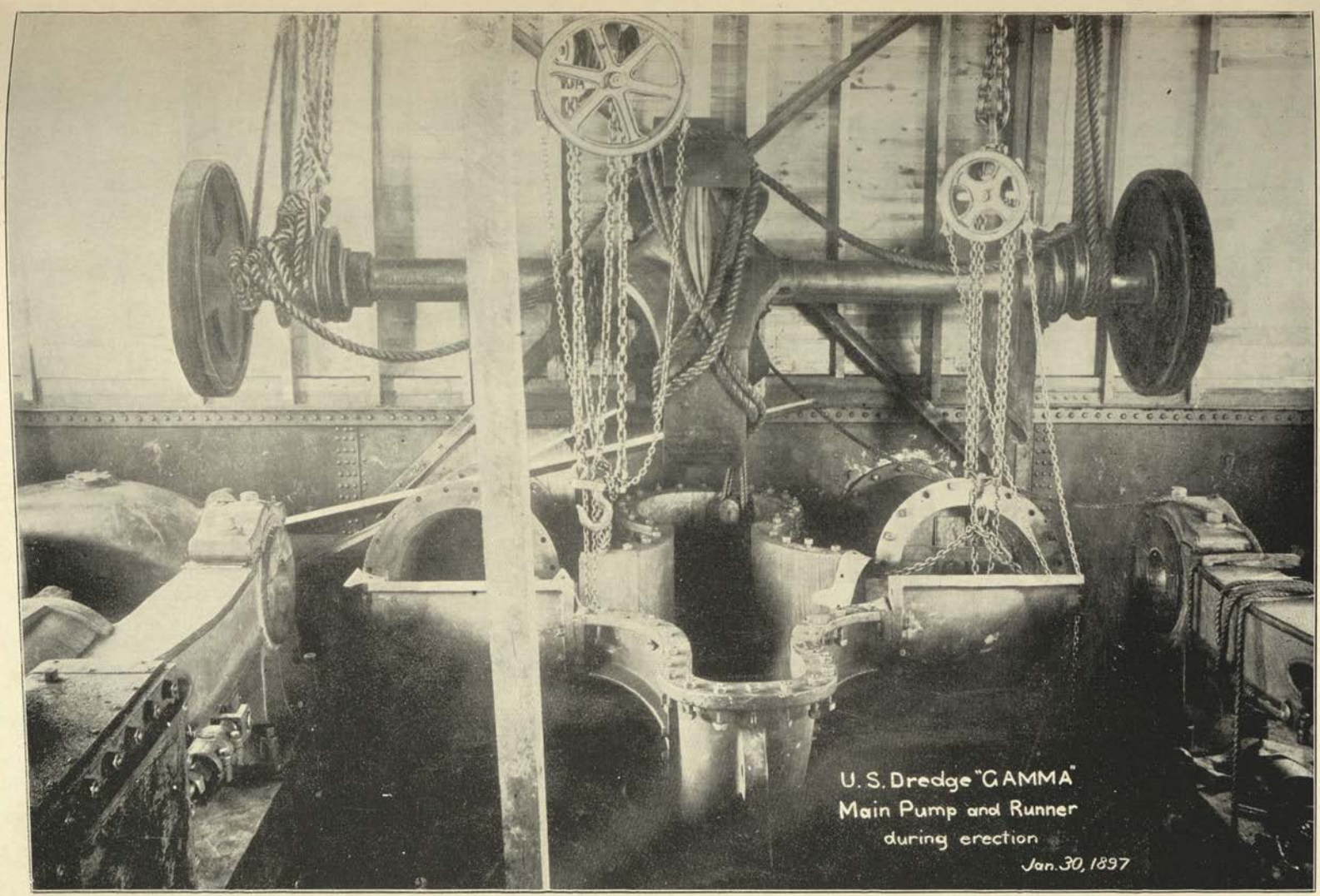
Dredge Gamma.

The Act of Congress of June 3, 1896, was the first to formally recognize and require the use of dredge boats as an adjunct to the permanent improvement of the Lower Mississippi. This formal recognition of the necessity of temporary relief for low water navigation resulted in the early construction of four more dredges.

"The contract for the Gamma was let in July 1896 to the Bucyrus Steam Shovel and Dredge Co., South Milwaukee, Wis. The capacity required was 800 cubic yards of ordinary river sand per hour, delivered through 1,000 feet of pipe with a centrifugal pump. The price paid was $85,530·00 and time fixed for completion was nine months. The Gamma was in actual work throughout the low water season of 1897, and was found to be very satisfactory both in capacity and economy.

"The hull is of steel, 138 feet long over all, 38 feet wide and 8 feet deep. There is a well at the bow $32\frac{1}{2}$ feet long in which the suction is placed.

"The framing of the hull consists of 12-inch channels stiffened with I-beam keelsons. Cross bulkheads divide the hull into two compartments, one for the boiler and the other for the engines. These are surrounded by water-tight compartments and are decked over.



U. S. Dredge GAMMA. Main Pump and Runner during erection. Jan. 30, 1897.

"The main dredging pump is located in the forward part of the engine room. It is a centrifugal with 24-inch suction inlet on each side and a 34-inch discharge at the bottom. The runner is 5 feet 9 inches in diameter and has four blades. It revolves at a speed of about 150 revolutions per minute. The casing is split horizontally through the axis so that the upper half can be removed in making repairs. It is of cast-iron from $1\frac{3}{4}$ to $2\frac{1}{2}$ inches thick. The shaft passes through the pump and has a bearing on each side of the casing. At these bearings the shaft is 8 inches in diameter.

"The pump is driven by a cross compound condensing engine with an independent condenser. The high and low pressure engines are horizontal, and are connected to two disc cranks set at right angles and keyed to opposite ends of the pump shaft. The high pressure cylinder is 18 inches and the low pressure $32\frac{1}{2}$ inches in diameter; the stroke is 22 inches. The high pressure cylinder has an adjustable cut-off with a hand adjustment to regulate the point of cut-off. Expansion relief valves are provided for the low pressure cylinder. The engines develop about 500 H. P. with boiler pressure of 140lbs.

"The jet pump is of the centrifugal type with 18 inches suction and discharge. It supplies the water to stir up the sand at the suction head. The runner has four arms with steel tips running as close as practicable to the casing to obtain the greatest available pressure. The pump and its engine rest on a common bedplate and have a flange-coupled shaft for pump and engine. The engine is a compound condensing engine of the marine type; the high pressure cylinder is 12 inches and the low pressure 22 inches diameter with a common stroke of 14 inches. The crank shaft has the crank set at right angles. The cylinders have plain slide valves. All parts are provided with automatic apparatus for lubrication.

"The air pump is horizontal with single steam cylinder 10 inches in diameter, air cylinder 18 inches diameter and 18-inch stroke. The condenser receives the steam from both main and jet pumps and is so arranged that the steam can pass directly to the atmosphere. The overflow from the condenser passes through a chamber, forming a hot-well for the boiler feed pumps. There are two feed pumps and one fire pump, so arranged that any one of them can be connected with the feed-water pipe or the fire hose. These pumps are vertical, duplex, outside-packed plunger pumps, with $7\frac{1}{2}$-inch steam cylinders, $4\frac{1}{2}$-inch water plungers and 8-inch stroke. An ordinary sand filter, with alum as a coagulent, is provided to filter the water used in the galley and cabin. A separate pump forces the water through the filter to a tank on the roof, and from there it is piped to various parts of the boat.

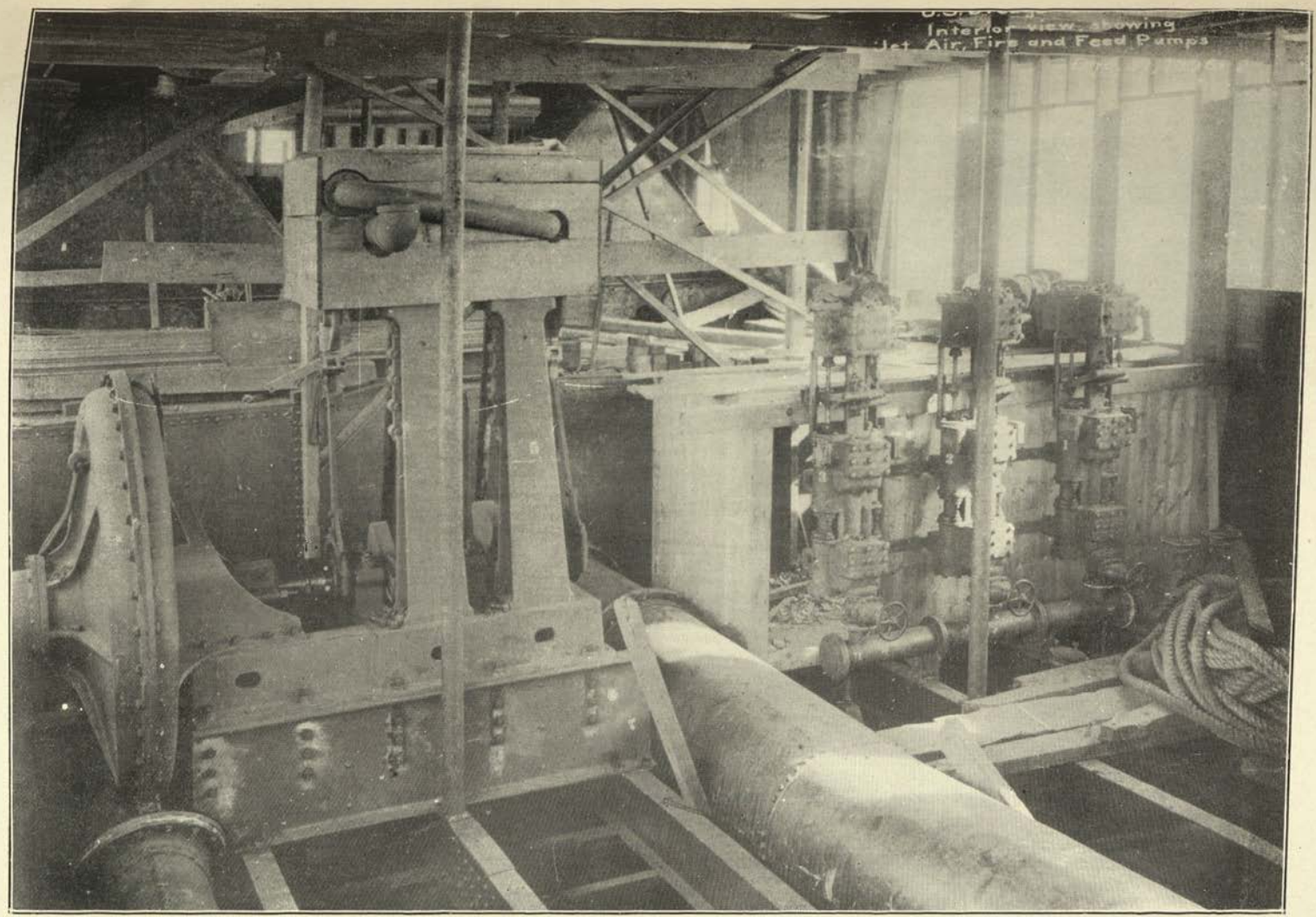
"The main hauling winches are located on opposite sides of the boat near the bow. They are driven independently and are provided with fast and slow feed controlled by clutches. The drums are 42 inches in diameter and 42 inches long, which gives space for 1,200 feet of $\frac{3}{4}$-inch wire rope. Each drum is driven by a pair of 7 × 7-inch double cylinder engines with cam reverse, and the power is transmitted through a combination of worm and spur gearing. The movement is

controlled by means of a brake wheel and strap. The speed ratio is 81 to 1 for fast and 493 to 1 for slow speeds. The hoisting engine for raising the suction pipe has a drum 24 inches in diameter and 24 inches long. It is fitted with brake, spur gear, pinion, clutch and shifting device. This engine also operates a shaft terminating in gipsy heads, which can be used in lieu of the capstans. The whole is driven by a pair of horizontal, double-cylinder, 8 × 10-inch plain, slide-valve engines, provided with steam reverse.

"The anchor spud is hoisted by means of an upright, single-acting steam cylinder, 18 inches in diameter and 6 feet stroke. The piston is attached to a cam clamp at its upper end, which grips and holds the spud against the slides. Steam enters at the bottom of the cylinder through a three-way valve, raising the piston and spud to the height of its movement. When the valve is turned to the exhaust port the piston and clamp descend, the spud being supported by a rack and pinion. The pawl locking the pinion is hinged between its centre of movement and point, and the tripping is effected by making the pawl buckle on itself so that the point turns under. This releases its hold and allows the spud to drop.

"Steam for the above-described plant is furnished by six boilers 48 inches in diameter and 28 feet long, with five 11-inch flues in each. These boilers are arranged in two batteries so that they can be used separately if desired. They are designed to carry a pressure of 140lbs. The fire-bed and ash-pan rest directly on the keelsons. Directly in front of the fire doors are coal bunkers having a capacity of 40 tons The bottoms of the mud drums are below the water-line, hence a special cleaning device is provided by means of a tank set between the keelsons under the mud valves. The mud and water remaining in the drums are drawn off into the tank, and then syphoned out. The feed water is heated by passing through two pipes hung in brackets from the sides of the parting wall between the two battery furnaces.

"The two intake pipes at the pump casing run forward to the suction head. They are hinged to the boat at the bow by two flanges connected by a pivot pin on the lower side and provided with a circular stuffing-box, making a radial joint that will allow the suction to be lowered to a depth of 15 feet. Outside of the joint the pipes and suction head are framed together and rigidly connected so as to form essentially one piece. At the suction head the pipes are 11 feet apart from centre to centre. The suction head for each pipe is 8 feet long and they are 3 feet apart, forming one suction head 19 feet long over all. The suction head proper has two inlets, one for the upper and one for the bottom intake, and between the two is a triangular pressure chamber running the whole length of the head. This connects directly with the jet pump. This chamber has nine $2\frac{1}{4}$-inch nozzles through which the water from the jet pump is forced with sufficient pressure to loosen the sand in front of the suction. The discharge pipe is 34 inches in diameter. It runs from the bottom of the pump casing along the floors between the two central keelsons under the partition walls. Between the batteries of boilers, and



U. S. Dredge "GAMMA." Interior View showing Jet, Air, Fire and Feed Pumps. Dec. 31, 1896.

through the stern of the hull, with the centre of the pipe 4 feet above the bottom of the hull at its exit. Near the pump the entire pipe is below the water-line, and the priming is done by means of a steam syphon at the top of the pump casing. The floating discharge pipe is 1,000 feet long, divided into 20 sections, each 50 feet long. They are made of $\frac{1}{4}$-inch tank steel. The pipes are floated by means of 40 cylindrical pontoons, each 23 feet 9 inches long and 30 inches in diameter. These are made of $\frac{3}{16}$-inch tank steel. They are attached to the discharge pipe by means of truss frames constructed of bar and angle irons, so designed as to receive and clamp the discharge pipe and carry the pontoons on either side. The pipe line is attached to the hull section of the discharge pipe by means of a male and female bevel-flanged coupling, a davit being used to swing the floating pipe into position.

"The hull has a cabin 97 feet long, and 29 feet wide, which protects the machinery and provides quarters for the crew. There is also a repair shop, provided with a lathe, drill press, emery grinder and other appliances needed in making ordinary repairs. An electric plant furnishes light for one 4,000 candle-power search-light, four arc lights of 1,200 candle-power each, and 75 incandescent lamps of 16 candle-power each.

"All the winches, the spud-hoist and the search-light are manipulated from the operating room. This dredge is towed from point to point, and while dredging is operated similarly to the Alpha.

Four 10-inch and four 12-inch hydraulic piles 33 feet long are provided, similar to that shown.

"This dredge was tested near St. Louis, Mo., in August, 1897, and, after the completion of the tests, she was used in actual dredging between Cairo and Memphis until early in December of the same year. The general efficiency tests, called for by the contract, required that the dredge should be operated 60 working days of 12 hours each in water from 5 to 15 feet deep, and with sand of such different degrees of coarseness as will be found on the low-water bars. After this had been done and the machinery found satisfactory, then 20 capacity tests were required to be made with the suction at different depths. This last requirement was considered filled when the total amount pumped per hour divided by 20 was equal to or exceeded the required capacity of 800 cubic yards per hour.

"The weights of the principal parts are as follows: Hull, 323,328lbs., cabin, 117,449lbs.; Main pump and engines, 74,722lbs.; jet pump and engines; 21,717lbs.; auxiliary engines, drums, levers, etc., 46,937lbs.; air, feed and fire pumps, 15,695lbs.; electric light plant, 7,700lbs.; boilers and accessories 325,911lbs.; suction head, 49,534lbs.; floating discharge pipe and pontoons, 244,916lbs.; hull fittings, 31,580lbs. Total, 1,019,623lbs. The working draft of the dredge is about 46 inches.

"Construction was begun in June, 1896, and the dredge was practically completed in March, 1897."

Dredge Delta.

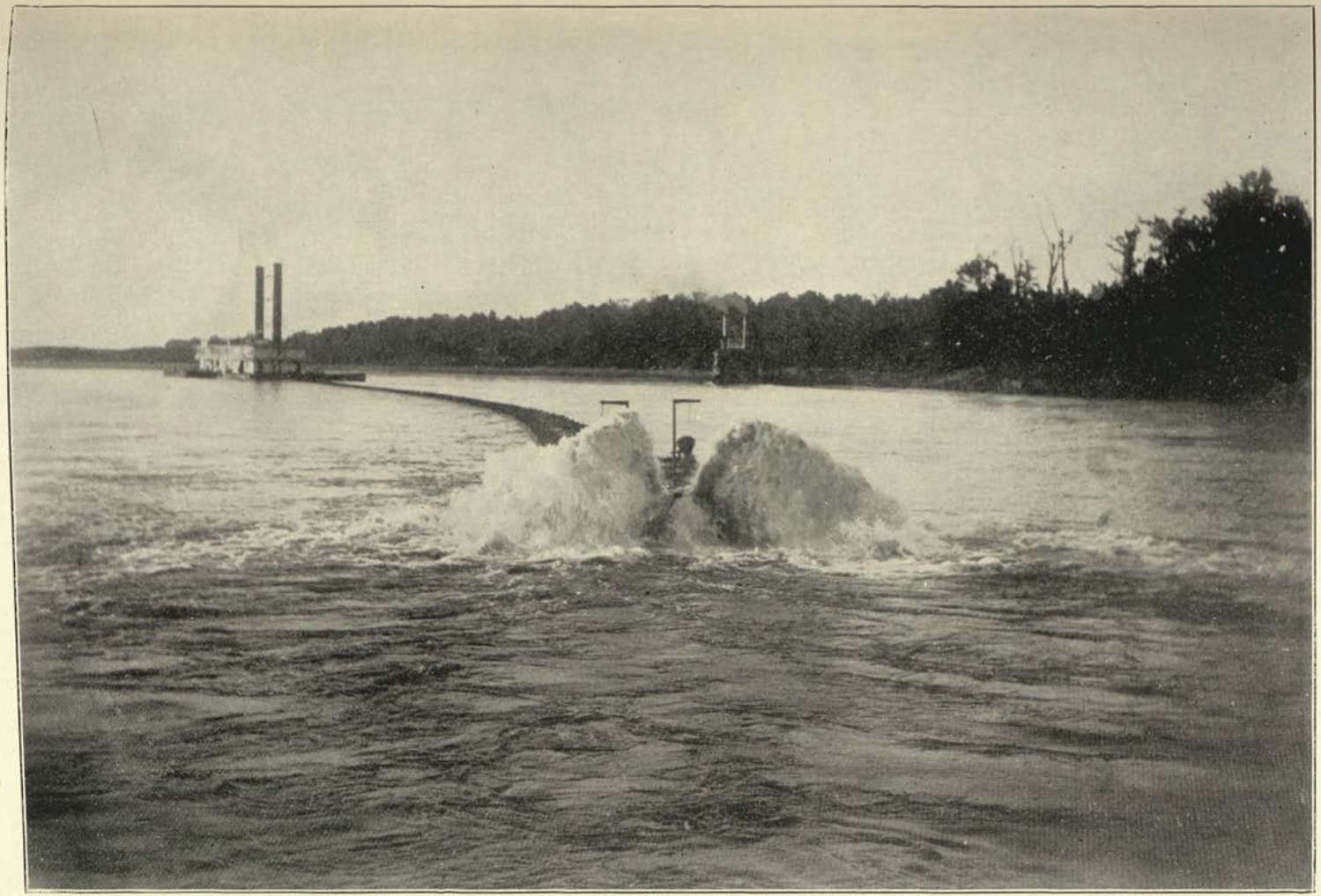
The dredge Delta was constructed under contract with the New York Dredging Co., who sublet the construction of different parts to various manufacturers and builders of machinery. The contract price for this dredge was $ 124,940. It differs from the Gamma chiefly in having a mechanical agitator instead of jets, in its hoisting and hauling winches, and in the form of pump. Its capacity is also somewhat greater. Its construction was begun in June 1896, and it was practically completed by the end of June 1897. After the tests were finished, the dredge was used in removing sand bars below Cairo throughout the low-water season of 1897.

"The hull is of steel, 175 feet long, 38 feet wide, and 8½ feet deep. A fender 24 feet long is carried around the suction, making the boat 199 feet long over all. The bow and stern of the hull have short rakes, and the midship section is rectangular. The frames of the hull are 22 inches apart between centres. Angles are used for the deck beams and Z-bars for the floors. There are two longitudinal bulkheads running the full length of the boat, and five cross bulkheads. They are all made of $\frac{5}{16}$-inch plate, with double angles at top and bottom. All are water-tight and have a syphon in each of the compartments. The thickness of the side plating of the hull is $\frac{3}{8}$-inch and of the other hull plating $\frac{5}{16}$-inch. It is all laid fore and aft, is lapped and single-riveted, except on deck, where the seams are planed and butted and fastened with 6-inch butt-straps single-riveted. Cross seams are similarly butted and riveted.

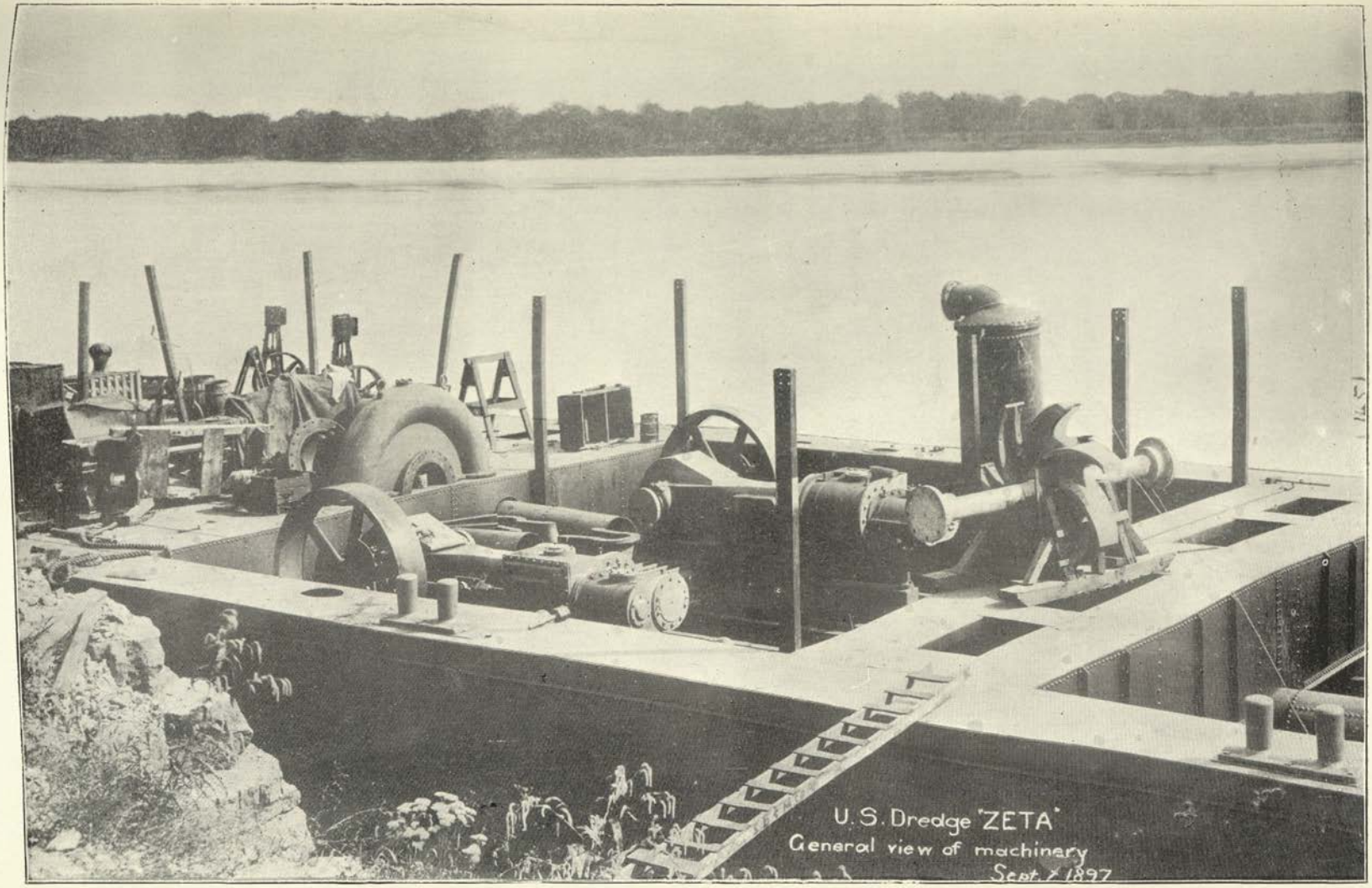
"Special foundations of 12-inch I-beams are provided for sustaining the heavy machinery and boilers. The boat is provided with a cabin 156 feet long, which protects the machinery and furnishes quarters for the crew. The operating room is at the forward end of the cabin, and is fitted with levers and brakes by means of which the boat is manœuvred.

"The dredging pump is different from those on the dredges heretofore described in the shape of the casing and the runner. The runner has five blades 22 inches wide, and is 7 feet in diameter. The edges run close to the casing, but the runner is not concentric with the casing, hence the outer ends of the arms are nearer one side of the casing than the other, the widest space being at the bottom, and the space being nearly cut off by a projection in the casing at the upper side of the discharge opening.

"The axis of the pump is parallel to the axis of the boat and lies over the centre line of the same. The thickness of the sides of the casing is 2 inches, and that of the outer circumference is 3 inches. It is lined on the inner side with steel plates fastened with counter sunk bolts. This lining can be renewed when worn out. The shaft of the runner is of forged steel 7¼ inches in diameter and 7½ feet long. It is fitted to the runner by a taper joint secured by a cap nut and two keys.



Veiw of Dredge in operation. Looking at end of Discharge Pipe.



U. S. Dredge Zeta. General View of Machinery. Sept. 7, 1897.

The shaft has one long bearing through the aft side of the casing. It is provided with water bushing under pressure to keep the sand out of the bearing.

"The sand pump is driven by a vertical, inverted, two-crank, compound condensing engine, with 22 and 48-inch cylinders and 24-inch stroke. It is fitted with a piston and slide valve and has an adjustable cut-off for the piston valve. The cylinders are supported by two cast-iron back frames of box section, and four taper-steel front columns $2\frac{3}{4}$ and $3\frac{3}{4}$ inches in diameter. The bedplate is of cast-iron, box-girder pattern, 8 feet 9 inches long by 8 feet $9\frac{1}{2}$ inches wide over flanges, and $20\frac{1}{2}$ inches deep from centre of shaft It has four babbitted journals 13 inches long and $8\frac{1}{8}$ inches in diameter. The steam chests are reached by means of a stairway and gallery. The usual accessories in the way of relief valves, drains, lubricators, etc., are provided. This engine was designed to develope 800 H. P. at 140 revolutions per minute, with a boiler pressure of 100lbs. and a vacuum of 25 inches.

"The air pump and jet condenser has a steam cylinder 12 inches in diameter, a water cylinder 18 inches and 24-inch stroke. The condenser is mounted vertically over the water cylinder. The air cylinder is copper-lined 18 × 24 inches and the plunger is packed with soft packing. The valve seats are brass and the valves are of hard rubber. A brass spray-cylinder throws the water out in jets.

"The engine which drives the cutters is horizontal, two-cylinder and non-reversible, all attached to a sliding steel frame, which moves back and forth in guides as the cutter is raised or lowered. This is necessary because the shaft which drives the sprocket chain is not in the axis of motion on which the suction and cutter revolve. The whole engine, with its frame, follows the motion of the shaft, so that the gear and pinion are always engaged. To admit of this motion, the steam pipes are provided with slip joints. The cylinders of this engine are $12\frac{1}{2}$ inches in diameter and have a 15-inch stroke, with the locomotive type of slide valve. It operates the cutters through spur gears and a sprocket chain.

"The fire pump is duplex, with two steam cylinders 8 inches in diameter and two 5-inch plungers with a stroke of 10 inches. The suction is 5 inches in diameter, and the delivery 4 inches. This pump furnished water to all the journals where water pressure is used to keep out sand. The feed pump is also duplex, with two steam cylinders 7 inches in diameter, two plungers $4\frac{1}{2}$ inches in diameter, with a stroke of 8 inches.

"A pressure filter 7 feet in diameter, with a capacity of about 65 gallons per minute, is provided. A special 3 by 4-inch engine is used to revolve the cleaners.

"A 7 by 9-inch vertical engine is provided to run the machines in the repair shop and the electric generator.

"There are two winding drums located forward of the sand pump, one on the starboard and the other on the port side of the hull. These are 42 inches in diameter and 42 inches long, mounted on a 6-inch shaft with two bearings in the main pillow-blocks carrying a 48-inch gear wheel at one end, and an 84-inch gear wheel at the other. These drums are provided with clutches and

brakes, and are driven by two independent double-cylinder, horizontal engines with 10-inch by 12-inch cylinders.

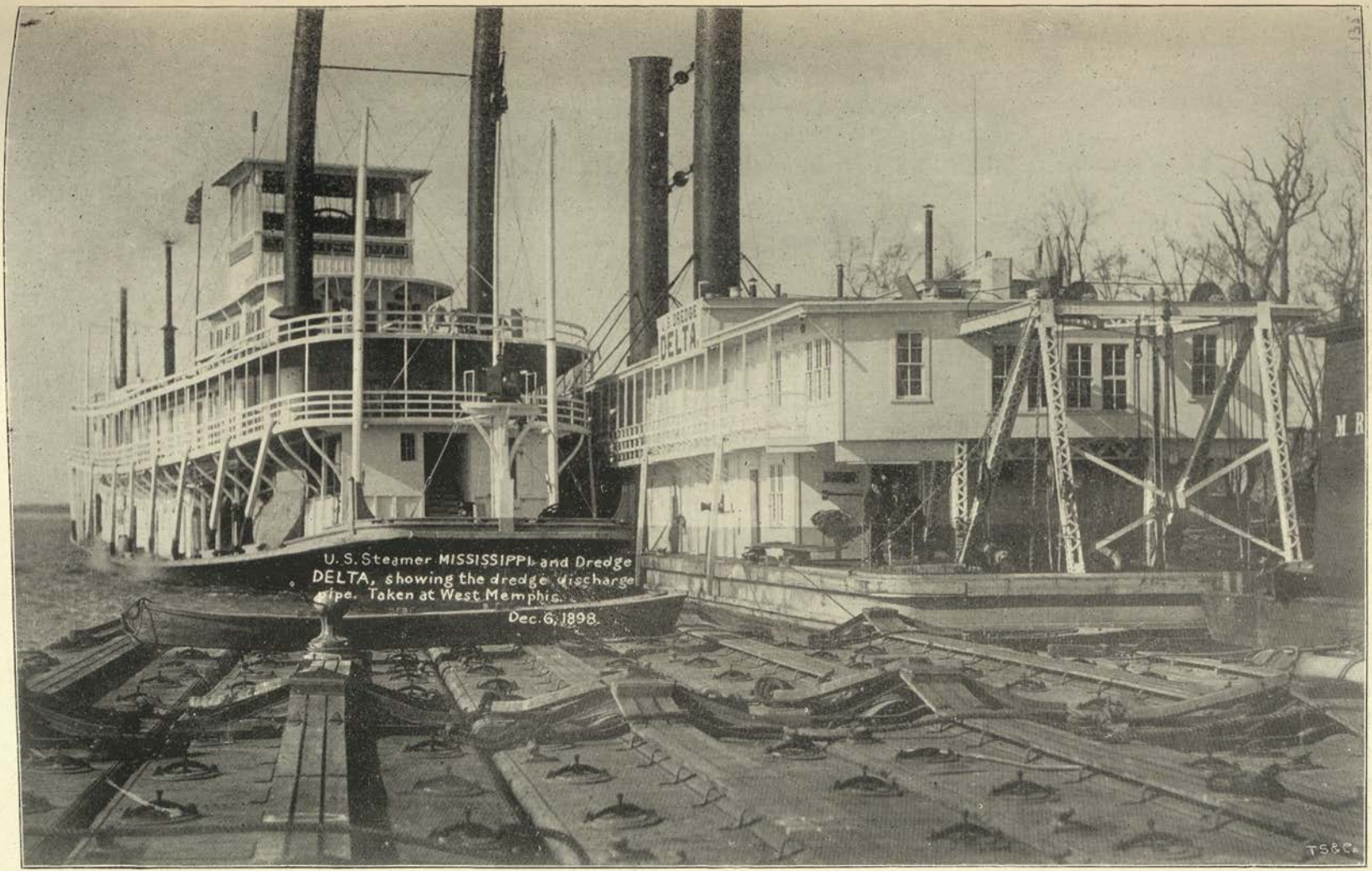
"The ladder hoist for raising and lowering the suction, and the spud hoist for raising the spud, each have drums 24 inches in diameter and 24 inches long. The former is on the starboard, and the latter on the port side of the boat. The cables from these drums lead to the roof and thence out through sheaves to the ladder and spud. These drums are operated by the same engines that operate the winding drums.

'Steam is supplied by four Heine safety boilers rated at 250 H. P. each. These boilers have two shells 36 inches in diameter and 19 feet 4 inches long; two water legs of flanged and riveted sheets held by hollow stay bolts; 140 lapwelded tubes 3½ inches in diameter and 16 feet long, and one submerged movable mud drum in each shell. These boilers are erected in two batteries on the main deck near the aft end of the boat. For each battery there is one stack, 68 inches in diameter and 64 feet high above the grate. The feed water is heated by passing through a heater with a shell 3 feet 1½ inches in diameter, fitted with 114 corrugated copper tubes 1½ inches in diameter and 78 inches long. This heater is situated in the centre of the boat between the boilers and the main engine. The main steam pipe is 6 inches in diameter, the feed pipe 4 inches and the drip, blow-off and safety pipes are 2 inches in diameter.

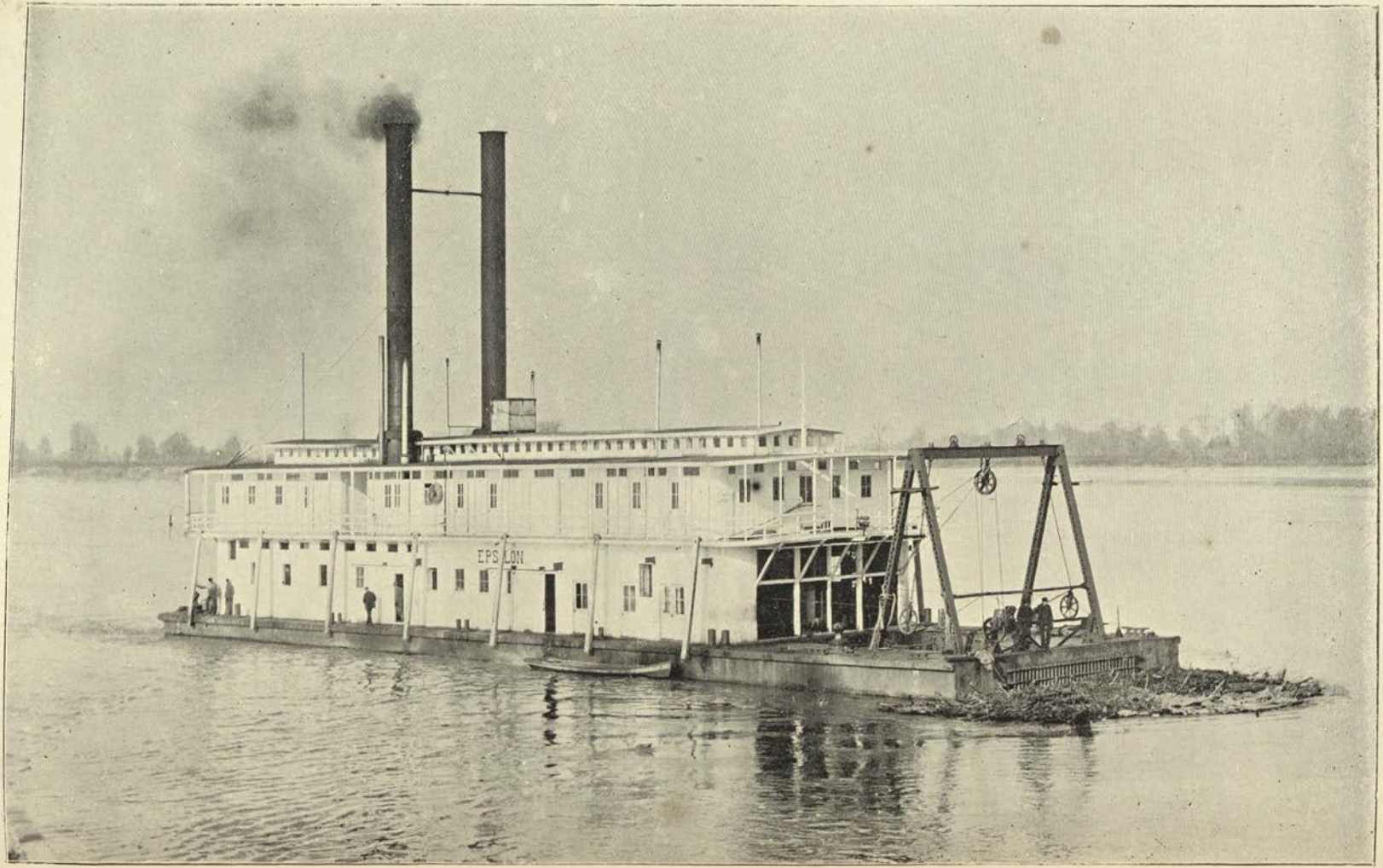
"The intake of the sand pump is from one pipe 34 inches in diameter, entering in the axis of the pump at the forward side of the casing. This single pipe runs 25 feet to the forward bulkhead and there branches into two pipes, each 24½ inches in diameter, which separate and pass through the bow of the boat below the water-line 9 feet apart. These two pipes turn to the right and left square along the outside of the bow and then turn forward again, and each branch separates into two pipes 17½ inches in diameter, which connect with the suction head. The whole is framed together so that the four pipes, suction head and cutters are raised and lowered together as one piece. Instead of a radial slip joint for the suction pipes, as used on the dredges already described, there is a vertical flanged joint in the horizontal part of each pipe next to the bow, and the revolving pins that sustain the weight of the aft end of the suction are placed in the prolonged axes of these pipes.

"The cutter for loosening up the material is placed at the outer end of the suction head. It has twenty-two cast-steel wheel cutters, each having four blades mounted on a steel shaft 6⅞ inches square. This shaft is driven by the cutter engine by means of two steel sprocket chains, at a rate of about eight revolutions per minute.

"The discharge outlet is on the starboard side of the casing near the bottom, and leaves the pump at right-angles to the intake. After leaving the pump the pipe rises so that the centre is slightly above the axis of the pump, and runs aft parallel to the side of the hull until it passes the main engine. Here it bends



U. S. Steamer Mississippi and Dredge Delta, showing the Dredge Discharge Pipe.
Taken at West Memphis, Dec. 6, 1898.



U. S. Dredge "EPSILON." General View.

over to the centre line of the hull, and the centre of the pipe drops about 11 inches below the water-line and runs straight aft under the boilers, through the stern, where the floating pipe is coupled on.

"The floating discharge pipe is 1,000 feet long, with the usual rubber coupling at intervals of 50 feet. There are pontoon floats on each side of this pipe, U-shaped in section, with the flat side closed, and they sustain the pipes in yokes which are firmly attached to the floats. There is a baffle plate at the end of the pipe line.

"The dredge is provided with sixteen hydraulic piles, six of which are 10 inches in diameter and 38 feet long, and ten are 6 inches in diameter and 25 feet long.

"The various parts of the winding machinery can be handled and moved by means of a 5-ton travelling crane. A traveller is also provided, with which to move the pump and main engine. The repair shop contains a screw-cutting engine-lathe, a drill press, a blacksmith's forge and a full set of tools.

"The boat is equipped with one search light, two arc lights and 100 incandescent lamps.

"The weights of the various parts of the dredge are about as follows: Hull, 489,500lbs; main pump and engine, 105,568lbs.; cutter engines and machinery, 45,000lbs.; winding engines and machinery, with extras, 47,000lbs.; air, feed and fire pumps, with extras, 11,900lbs.; electric plant engines, dynamos, etc., 4,275lbs.; heater, separator and filter, 21,500lbs.; derrick, ladder, travellers, tackle sheaves, bolsters, tools, etc., 44,000lbs.; capstans, spud, piping and fittings, deck fittings, etc., 42,000lbs.; discharge and suction pipes pertaining to hull, 51,300lbs.; boilers, stacks, etc., complete, 320,000lbs.; cabin, complete, 180,000lbs. spare parts for main pump, etc., 13,565lbs.; Total approximate weight, 1,375,608lbs.

"The weight of the floating pipe line is 221,477lbs.

"This dredge was launched on February 20th, 1897, and the tests were completed August 11th, 1897."

Dredges Epsilon and Zeta.

The construction of the dredges Epsilon and Zeta was begun early in January, 1897. They were built under contract with the Springfield Boiler and Manufacturing Company, of Springfield, Ill. The work done by this company at its own shops was confined chiefly to the hulls, floating pipe lines, boilers, and other plate work. The pumps, engines, etc., were sublet to other manufacturers.

The stipulated capacity of these dredges is 1,000 cubic yards of ordinary river sand per hour, dredged from a maximum depth of 15 feet and delivered through 1,000 feet of floating pipe.

The dredges are alike throughout, except that the Epsilon has water jet agitators and the Zeta has mechanical agitators. The

contract price of the Epsilon was $102,000, and of the Zeta $106,000.

"The hulls are of steel, 157 feet long, 40 feet wide and 7½ feet deep. There is a well at the bow 35 feet long, 18 feet wide at the hull, and 22½ feet wide at the forward end. There are two open spaces in the hull, one for the engine and pumps, and one for the boiler and coal bunkers. All other parts of the hull are decked over.

"The floor beams are 12-inch steel channels, 25lbs. per foot. The frames are 3 × 4-inch angle irons, 11lbs. per foot, and are spaced 24 inches between centres throughout the engine compartment, and 30 inches for the other parts of the hull. There are ten 15-inch I-beam keelsons, the two outer ones weighing 55lbs. per foot and the others 45lbs. per foot. These keelsons are riveted to the floor beams.

"The greater part of the hull plating is ⅜ inch thick. The centre strake of the bottom plating, the upper strake of the side plating and the bow end plates are ⅜ inch thick. The deck plating is ¼ inch thick. The butts of all outside plates are planed so as to fit closely. The longitudinal seams are lapped 2½ inches and single riveted. The plates are butted on the transverse seams and riveted to butt straps ⅛ inch thicker than the plates.

"The hull is divided into 11 watertight compartments by two longitudinal bulkheads and five cross bulkheads.

"The frames in the engine and boiler pits are covered with $\frac{3}{16}$ inch plates. Special beams and angles are provided for supporting the machinery.

"The main sand pump is located on the axis of the hull in the forward part of the engine pit. It is similar in form to that on the Gamma. That is to say, it has a divided suction, consisting of two 24-inch pipes, admitting the water on both sides of the casing, and the shaft of the runner extends through the casing with a bearing at each side. The main bearings of the pump runner are protected from sand by means of a ring of water under pressure supplied by the fire pump. The discharge is from the bottom of the casing and is 32 inches in diameter. The pump runner is 5 feet 9 inches in diameter and has seven blades 11⅝ inches wide at the outer ends. It is to be run at a speed of about 160 revolutions per minute. Pressure gauges are provided to show the suction and delivery heads.

"The main engines which operate the pump are connected to the ends of the shaft passing through the pump runner by means of flanged couplings. There is a tandem compound engine at each end of the shaft, each having cylinders 16 × 26 inches in diameter and an 18-inch stroke. The cranks are set at right angles to one another. These engines are balanced in a horizontal direction and automatic governors are provided to regulate the speed. They are designed to develop 650 H. P. at about 180 revolutions per minute with a boiler pressure of 150lbs.

"The engine sub-bases connect with and are bolted to the base of the pump-casing, thus forming a common base for the whole.

"The Epsilon has a 15-inch centrifugal jet pump, operated by a vertical cross compound engine with cylinders 12 and 22 inches in diameter and with 12-inch stroke. The engine is on the same base as the pump and is directly connected with a flange coupling. This pump is on the starboard side at the rear end of the engine pit. The intake, 18 inches in diameter, is on the side, and the discharge pipe, 15 inches in diameter, leaves the casing at the bottom and leads to the pressure chamber at the suction head.

"Two boiler feed pumps are located in the engine pit opposite the jet pump, near the port side of the boat. The cylinders are 8 and 4½ inches in diameter and the stroke is 10 inches. There is also a fire pump with cylinders 10 and 5 inches in diameter with a 10-inch stroke. These pumps are arranged with suitable cut-off valves, so that they can be used together or singly, as may be desired.

"The winding engines and the hoisting and hauling drums are located near the bow of the boat. The hauling engines for controlling the movement of the boat are located one on each side of the bow. The drums are 42 inches long and 42 inches in diameter, and hold about 1,200 feet of ¾-inch wire rope in two laps. Each of these drums is operated by an 8 × 8-inch double cylinder engine provided with a link reverse and suitable clutches and brakes, giving fast or slow motion, as may be required. The suction hoist is situated a little to the port side of the centre line of the hull. The drum is 14 inches long and 42 inches in diameter. It is operated by a double engine with 8 × 8 inch cylinders. The spud hoist is located just behind the anchor spud and on the starboard side of the centre line of the hull. It is also operated by an 8 × 8-inch double engine and is used for raising or lowering the anchor spud. The drum is 22 inches long and 42 inches in diameter. The operator stands on an elevated platform behind the winches and controls their movements by means of vertical levers.

"The repair shop is located between the operating room and the engine pit. It is provided with lathe, drill press, screw and bolt cutter, shaper, forge and an engine to run the several machines. A full set of machinist's and blacksmith's tools is also provided. In the same room is located the engine and direct-connected dynamo, furnishing light for all parts of the boat and also a powerful search light at the bow and two arc lights at the stern.

"On the Zeta the jet pump is omitted and a mechanical agitator for stirring up the material is used. This agitator consists of a vertical scraper or harrow attached to the front end of the suction head which is given an up-and-down motion by means of a bell crank. It is divided into two parts which are suspended in front of the port and starboard suctions respectively. A connecting rod or pitman extends from each agitator back to the rear end of the well, where it connects with a second oscillating crank operated by an engine with 10 × 14-inch cylinders. These engines are connected through gearing to a common shaft extending entirely across the boat. In order to lessen the danger of breakage

from snags or other solid obstructions, a shearing pin is provided at the angle of the forward crank which is so arranged as to shear off before strain can come on the agitator to break it. Mechanically considered, its movements are quite satisfactory. (Mr. Ockerson states that in the tests it was demonstrated that the capacity of the pump with this agitator was not much over half the capacity of the pump with jet agitators. Mr. Flad, however, subsequently points out that the test to which this agitator was put was much more difficult than that to which the jet was applied, and that the comparison made by Mr. Ockerson is unfair. He adds that, as a matter of fact, the Commission were advised to put both jet and mechanical agitator on this dredge.)

" Steam for the various machines described above is derived from six boilers located near the aft end of the boat. These boilers are 48 inches in diameter and 28 feet long, with three 11-inch and two 13-inch flues, and are designed for a working pressure of 140lbs. They are arranged in two batteries so as to be operated separately or together. Each battery has a smoke stack 44 inches in diameter and 70 feet high. The boilers are set below the main deck and rest on channel bars placed across the keelsons. The feed water is pumped through a heater which receives the exhaust steam from the main engines. A donkey boiler, 48 inches in diameter and 9 feet high, is also provided to furnish steam for the electric light and shop engines when the main boilers are not in use.

"The two suction pipes run forward from the pump casing, separating gradually until 12 feet apart at the bow. At this point a tight radial joint is provided, which connects the pipes in the hull with the pipes from the suction head, and admits of the vertical motion necessary for dredging at different depths. The suction can be lowered to a maximum depth of 15 feet. Outside the hull the two suctions are framed together rigidly and are handled as a single piece. The raising and lowering is accomplished by means of sheaves and tackle attached to a derrick frame located over the forward end of the suction well. A straining frame is provided so that when the suction is lowered to a suitable depth, it can be locked ; it thus relieves the tackle of the weight and maintains the suction at a constant depth. Each part of the suction head is 10 feet long, making the suction 20 feet wide over all.

"The Epsilon suction head has a pressure chamber on the underside at the front end connecting with the jet pump. Ten 3-inch jet nozzles are screwed into the front side of this pressure chamber, and serve to loosen and stir up the sand and induce the flow of material to the suction.

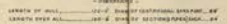
"The discharge pipe passes straight aft from the pump between the two central keelsons and rests on the floor beams for a distance of about 52 feet. From this point it rises gradually for a distance of 22 feet until the centre of the pipe is 4 feet above the bottom of the boat. Then it runs horizontally straight out through the stern, projecting far enough to couple on the floating pipe line. The pipe is flattened out near the pump casing so as to depress it below the water line and thus facilitate priming, which is done by using a steam syphon at the

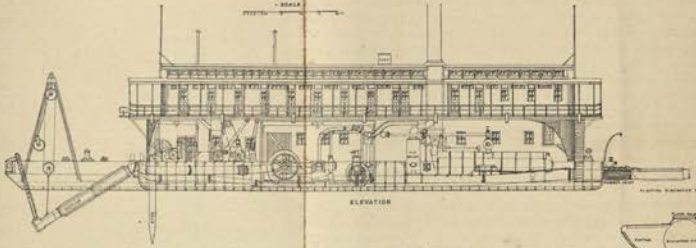
MISSISSIPPI RIVER COMMISSION

Office of the Secretary

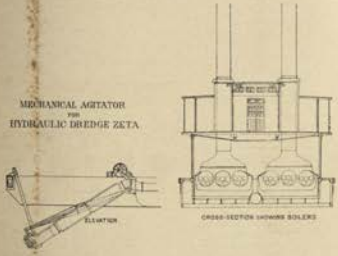
HYDRAULIC DREDGE EPSILON.

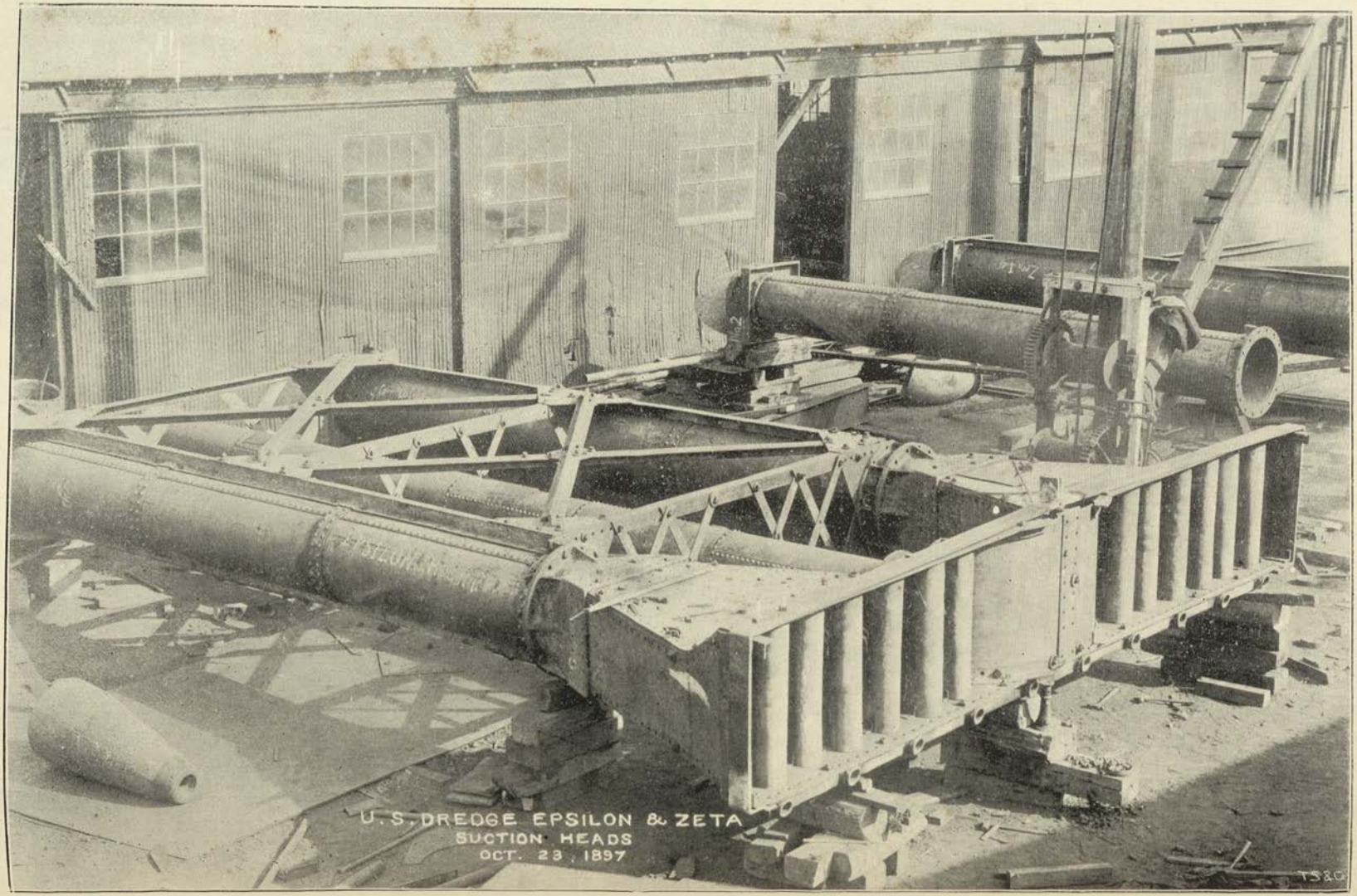
- DIMENSIONS -





MECHANICAL AGITATOR FOR HYDRAULIC DREDGE ZETA





U. S. Dredges Epsilon and Zeta Suction Heads.

top of the casing. (In Major Handbury's dredges 3 and 4, a special priming valve has been introduced at this point.)

"The floating discharge pipe is similar to those previously described, except that greater buoyancy is provided and the shape of the float is somewhat flatter. The pipes are built in 50 feet lengths.

"Travelling cranes are provided for the easy handling of the machinery of the engine room and the hoists ; and there is one steam capstan at each corner of the dredge. Steam syphons are provided for all the water-tight compartments. Six 10-inch and ten 7-inch mooring piles of the usual form are provided for each dredge.

"A velocimeter is provided for showing the velocity of flow in the discharge pipe. This consists of two vertical tubes which pierce the discharge pipe. They are set in the vertical plane passing through the longitudinal axis of the discharge pipe. About 5 inches below the upper inner surface of the pipe, $\frac{1}{4}$ inch tubes, 6 inches long, are inserted horizontally ; the one nearest the pump being open toward the pump to receive the pressure of flow and the other turned in the opposite direction. The upper ends of the vertical tubes connect with glass tubes attached to suitable scales. The difference in the height of the columns of water in the two tubes, when water is flowing through the discharge, gives the results from which the velocity of flow can be deduced.

"Weighing apparatus designed to show the percentage of solid matter passing through the discharge pipe is also provided. To accomplish this, a suitable length of the pipe is connected at each end by rubber thimbles which leaves the joints flexible. One end of this pipe is then supported by a weighing apparatus properly counterbalanced. An indicator is located where it can be readily seen by the engineer. The pointer is set so that it reads zero on the dial when water only is pumped. When sand is pumped the pointer will show on the dial the weight of same at any moment, and consequently the percentage of solid matter.

"Both dredges have cabins for the protection of the machinery and to provide quarters for the crew . . . . There are ample accommodations for a crew of 50.

"The weights of the various parts of each of these dredges are about as follows :—Hull, 442,388lbs.; main pumps and engines, 117,060lbs. ; cutter engine and agitators, Zeta, 25,000lbs. ; jet pump and engine, Epsilon, 19,000lbs. ; winding engines and machinery, 33,436lbs. ; fire and feed pumps, 8,100lbs.; heater, 4,925lbs. ; electric plant, 4,200lbs. ; derrick, A-frame, travellers, sheaves pipes and fittings, deck fittings, capstan, &c., 37,500lbs. ; discharge and suction pipes pertaining to hull, Epsilon, 54,447lbs. ; same for Zeta, 51,509lbs. ; boilerstacks, &c., complete, 195,000lbs. ; cabin complete, 120,000lbs. ; Total weight of each dredge, 1,057,118lbs. ; weight of floating pipe line, 325,000lbs."

Note.—In actual work neither the velocimeter nor weighing apparatus is found of any practical use.

Major Handbury's Dredge No. 2.

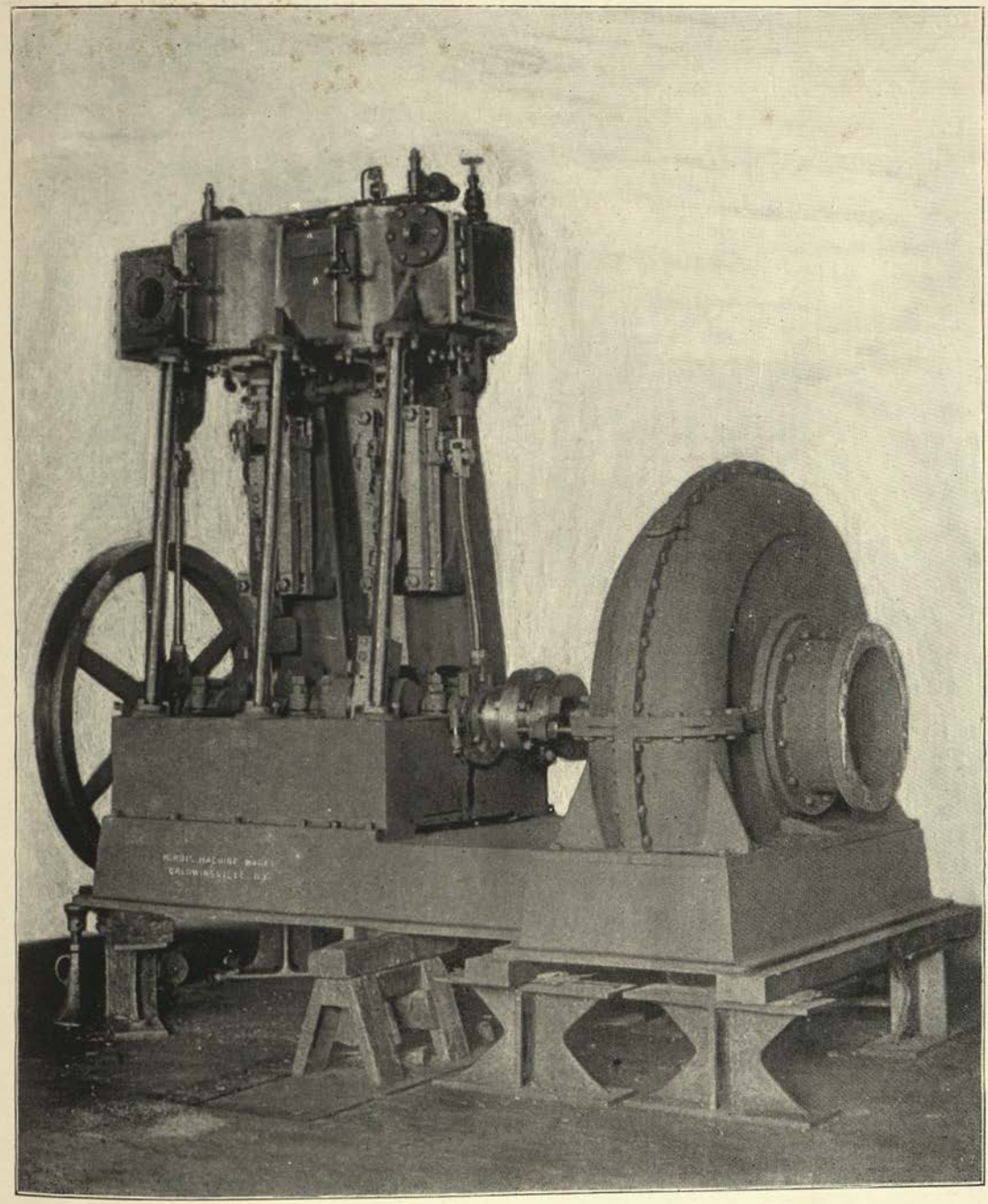
The first dredge used on the river between the Missouri and the Ohio for channel improvement was the jet dredge mentioned in the note on Channel Contraction Works. The next constructed was Major Handbury's dredge No. 2. It was hurriedly put together, making use of such parts of the plant as could be made available.

"One of the most recently constructed model barges used for transporting stone was selected, and given such additional strength by bulkhead timbers as was necessary to enable it to sustain the machinery to be placed upon it without vibration when in motion. This barge is 135 feet long with 28 feet beam, and has a 6 feet depth of hold. On it was placed a 20-inch centrifugal pump actuated by horizontal compound condensing engine, connected directly with the pump shaft. Diameter of high pressure engine, 11 inches; diameter of low pressure engine, 25 inches with 18-inch stroke. The pump and engine are upon the same cast-iron base. This machinery was purchased from Edwards & Co., New York.

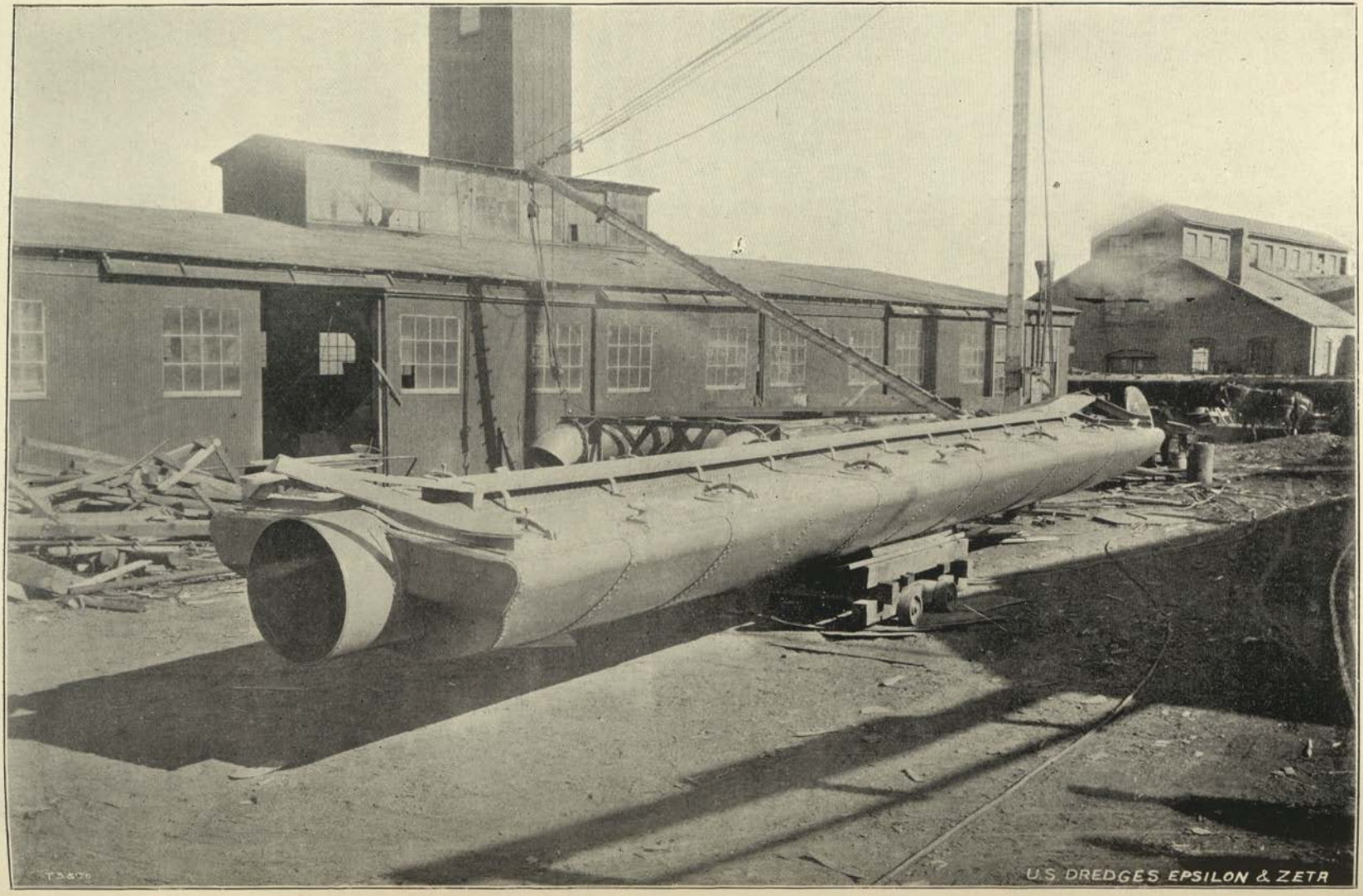
"Steam is furnished by three boilers, Mississippi river type, 48 inches diameter and 28 feet long, each having five flues 11 inches in diameter. The ordinary working steam pressure of the boilers is 140 lbs. The engines make 200 revolutions per minute and the pump discharges about 2,000 cubic feet of material. On the basis that 10% of this is sand, which is a very reasonable estimate, the dredge will excavate about 450 cubic yards per hour.

"The suction pipe is 20 inches in diameter from the pump out to the bow of the boat. At this point the pipe branches to the right and left, with a quarter turn 15 inches in diameter. At the ends of these is a stuffing box and another quarter turn which permits the pipe to extend down over the bow of the boat and into the water. These stuffing boxes allow each branch of the pipe to move in a vertical plane. At their lower ends these pipes separate by Y's into two branches, each 12 inches in diameter, and terminate in nozzle pieces with opening 30 inches × 6 inches. The two 15-inch pipes are tied together by suitable bracing and raised and lowered by means of a derrick with boom extending out beyond the boat. The hoisting power is obtained from a pile-driver engine taken from the plant. The same engine is used to haul the dredge ahead and keep it up to its work.

"Immediately at the pump the discharge pipe makes a quarter turn and is enlarged to 24 inches in diameter. It passes back through the boat and over the stern on to flat-boats, which support it for a distance of 500 feet. At the stern of the boat there is an S-shaped piece in the pipe, having a horizontal swivel joint, which permits the discharge to be made in any horizontal direction. Where the pipe passes from one flat to another, there is a short piece of para-rubber hose which permits a flexible motion. The flat-boats, on which this pipe is supported, are a part of the outfit of the plant used for low-water revetment. In the discharge pipe near the pump there is a priming valve used when starting the pump.



U. S. Dredge "Epsilon," Jet Pump and Engine.



Dredge Delivery Pipe.

"To operate the dredge, piles are driven on each side of the channel to be opened and at some little distance from it, lines are made fast to these and the dredge, and discharge pipe manœuvred by means of them.

"This dredge was not completed until the end of November about the time the river commenced to rise . . . It was operated experimentally for several days and all its parts thoroughly tested. It bids fair to be a very satisfactory machine. Its cost was $21,705·00."

Major Handbury's Dredges Nos. 3 and 4.

Dredge No. 2 referred to above has been termed a temporary experiment, constructed hastily to meet urgent requirements. Major Handbury, having made a special study of the subject of dredging, as applied to river bars, designed his dredges Nos. 3 and 4, which have large capacity and light draft, accommodation for the crew, and at the same time dispose of the material beyond the lateral limits of the channel to be improved. These dredges have now been at work for two full seasons, and have given very satisfactory results. In many particulars they differ largely from the dredges designed by the Mississippi Commission. Their main features may be briefly described in the words of Major Handbury as follows :—

"The hull is made of steel throughout and is 160 feet long, 40 feet beam and 6 feet 6 inches depth of hold. There is an opening or well at the bow, in which the suction pipes are placed 24 feet wide at forward end, 18 feet at after end by 34 feet long. The two projecting ends thus formed are tied together by a box girder. (The space between these ends is now spoken of as "the well.")

"There are two centrifugal pumps with suction and discharge openings 20 inches in diameter. The discharge pipe is immediately enlarged to 24 inches in diameter. The pumps are single suction, with interior lining capable of being conveniently removed when worn.

"Each pump is driven by a horizontal non-condensing compound direct-con, nected engine, 15-inch high pressure, 26-inch low pressure, with 18-inch stroke-capable of developing 300 actual horse-power, with approximately 200 revolution, per minute, under a boiler pressure of 140lbs. per square inch, and maintainings through the suction and discharge pipes, the velocity necessary to carry at least 20% of sand with 80% of water through 500 feet of discharge pipe.

"The steam is supplied by six boilers of the Mississippi River steam-boat type, each 48 inches in diameter and 28 feet long, and containing five flues, each 11 inches in diameter. The boilers are arranged in two batteries of 3 each, capable of being worked separately or together.

"With each main pump there is a jet pump for applying water under pressure through nozzles to the sand at the entrance to the suction pipes. The

jet pumps are of the Worthington type with compound engines capable of delivering 1,200 gallons per minute against a pressure of 65lbs.

"The suction pipe of each main pump has a diameter of 20 inches. It leaves the pump by a reverse curve, passes out through the hull, and by a radial joint down through the suction well, and terminates with a nozzle or suction head 10 feet wide and 20 inches high, and provided with screen bars or lobes. In order to present the opening in the most favourable manner to the sand, the suction head is slightly curved.

"There is one discharge pipe for each main pump. At the stern of the dredge there is in each pipe a reverse curve swivel joint by means of which the pipe beyond the dredge is slightly raised and can be changed in direction through an angle of 180 degrees. On the outside of the dredge the discharge pipes are in lengths of 24 feet connected by flanges ; each two of such lengths are connected by a coupling and piece of flexible rubber hose. The pipes are supported at every 25 feet upon steel pontoons, so arranged that they may swing under the pipe and present their narrowest dimensions to the current. Each discharge pipe is 500 feet in length and terminates with a baffle plate, for the purpose of steadying the pipe line while the material is going through it.

"Cabin accommodations are provided for a double crew consisting of 50 officers and men.

"The electric light plant consists of two 2,000 c. p. arc lights, one 4,000 c.p. focusing head light with reflector, 75-16 c. p. incandescent lamps, with the necessary engine, dynamo, switchboard, and other appurtenances and appliances for a complete first class outfit. All other outfit and appliances necessary to a complete dredge are provided. When occasion requires, it is intended that the dredge shall be in operation night and day. The output per hour will be 600 to 1,200 yards for each dredge."

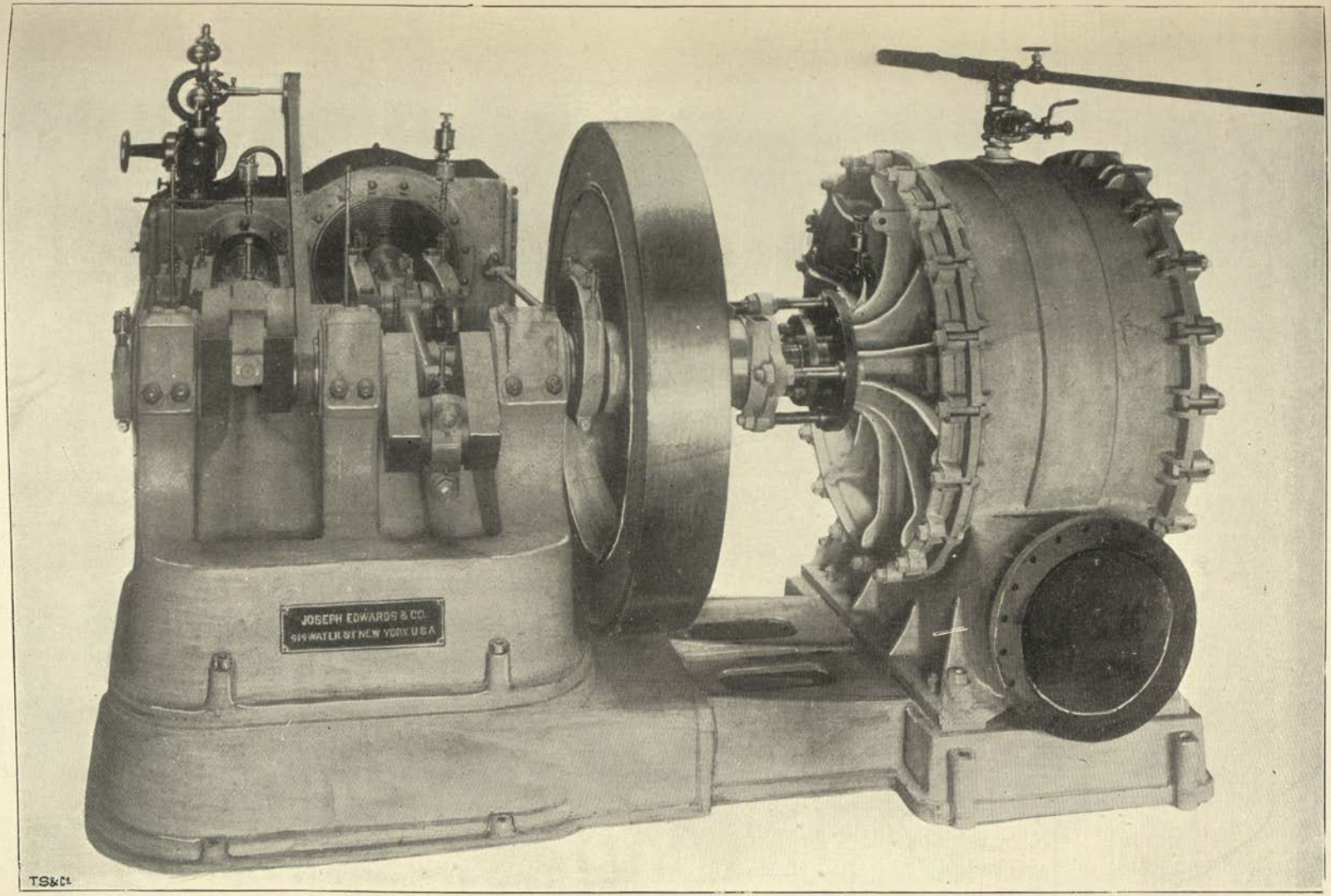
Four sheets of drawings showing the main features of above dredges are attached to the Chief of Engineer's report for 1897, Part 3, and a detailed specification of dredge No. 4 obtained from Major Handbury is attached as a separate appendix to these notes.

The original cost of the two dredges, Major Handbury's Nos. 3 and 4, built by the Bucyrus Co., South Milwaukee, Wis., was $204,800, or $102,400·00 each.

Improvements made in Major Handbury's Nos. 3 and 4.

After delivery and trial of No. 3, it was found necessary to make a number of changes and additions to these dredges to suitably equip them for their field work. The following are the most important alterations made :—

"A travelling carriage was built in the engine room, running both athwart ships and fore and aft on iron beams, so that the parts of the main pumps and engines can be lifted out and moved by chain blocks without setting up shears or



20-inch Edwards Cataract Pump.

supports. A shifting gear was made for the winch engines so that both can be handled at the same time by one operator. The blow-off pipes were provided with an extra valve. The large jet pumps were connected with the fire hose. The donkey boiler was supplied with a feed pump and heater. A brass top was put on the winch deck railing. A nosing of 2-inch half round iron was placed across the head to prevent the cutting of lines. Iron jackets were placed around the chimney casings, and the space between them and the casings filled with mineral wool. Additional chains and blocks were made for holding the suction pipes. A counter shaft was put up in the machine shop to change the location of the driving belt. A wedge ring was fitted to each discharge pipe near the swivel joint to change its direction ; a line of speaking tube was put up on each side from the forward deck to the stern, and others connecting the engine room with the boiler room and forward deck. . . . The cabin stairs were moved . . . the ceiling was removed so that the kitchen extended up to take in the transoms . . . A new hood was made for the blower and its speed increased by a larger pulley on the counter shaft. A lighter set of run boards was made for the pipe line and shorter pins for the couplings. To increase the buoyancy and stability of the pontoons iron wing boxes or compartments were bolted to each side, increasing the width of the pontoon from 8 to 14 feet ; these boxes were made of $\frac{3}{16}$ inch iron with frames of $2 \times 2 \times \frac{1}{4}$ inch iron, riveted cold and caulked with a pneumatic tool ; they were fastened to the pontoons with bolts made watertight with rubber washers."

All the above alterations were made on the dredges after delivery, excepting those referring to rearrangement of the cabin stairs, kitchen bulkhead and blow-off pipe which were carried out on No. 4 by the contractor during construction.

General.

Mr. Ockerson's paper also includes a description of the Dredge "Bayley" built as long ago as 1877 by Mr. Eads for use in the channel between the Passes and the Jetties. The Bayley is a self-propelling dredge about 200 feet long, 32 feet wide and 10 feet depth of hold. She pumps into spoil-bins forward of the engines, and then takes the silt out to sea or other dumping ground. Though built so long ago she is still in use but, owing to the great loss of time in transporting the dredged material, she could hardly be classed at the present time as an efficient machine for the lowering of bars in a river channel, and need therefore not be described here.

The results of efficiency tests of the different Commission dredges are given by Mr. Ockerson and are also to be found in the reports of the Commission for 1897 and 1898. In those reports will also be found detailed specifications and some plans of the several dredges.

The reader who is sufficiently interested is referred to them for any additional information he may require.

The statement on the following pages shows the principal features of the Commission dredge boats operating on the river below Cairo.

During the low water season of 1897, four dredges were at work on bars; the cost of operating them for the season was as under :—

Labour	$25,704·00
Fuel	13,474·00
Subsistence	7,587·00
Lubricants	971·00
Lighting supplies	215·00
Miscellaneous supplies	1,528·00
Office supplies	145·00
Hire of tow boats for moving plant	10,116·00
Preparation and moving into field	3,269·00
Moving to winter quarters at end of season ...	4,627·00
Cost of inspection and supply boat	10,555·00
Cost of operating two survey boats	8,674·00
TOTAL ...	$87,875·00

PRINCIPAL FEATURES OF SOME OF THE DREDGE BOATS OPERATING ON THE MISSISSIPPI RIVER BELOW ST. LOUIS.

———	GAMMA.	DELTA.	EPSILON.	Maj. HANDBURY'S No. 4.
HULLS.				
Material	Steel	Steel	Steel	Steel.
Length	138 ft.	175 ft.	157 ft.	160 ft.
Breadth	38 ft.	38 ft.	40 ft.	40 ft.
Depth	7 ft. 10 ins.	8 ft. 4 ins.	7 ft. 6 ins.	6 ft. 6 ins.
Draft	54 ins.	54 ins.	46 ins.	42 ins.
Displacement	640 tons	830 tons	665 tons	625 tons.
MAIN ENGINES.				
Number	1	1	2	2
Type	Horizl. Cross-Comp. Cond.	Vertl. Comp. Cond.	Horizl. Tandem Comp.	Compound Non-Condensing.
Diam. of Cylinders	18, 32 1/2 ins.	22, 48 ins.	16, 26 ins.	15, 26 ins.
Stroke	22 ins.	24 ins.	18 ins.	18 ins.
Revolutions per min.	150	145	180	175-200.
Steam Pressure	140 lbs.	160 lbs.	156 lbs.	120 lbs.
Indicated H. P.	475	800	650	300.
AIR PUMPS.				
Type	Single	Single	None	None.
Cylinder	10 ins.	12 ins.	.....	.....
Air Pump	18 ins.	18 ins.	.....	.....
Stroke	18 ins.	24 ins.	.....	.....
MAIN PUMPS.				
Number	1	1	1	2
Type	Double suction	Single suction	Double suction	Centrifugal (Edwards).
Diam. of Runner	69 ins.	84 ins.	69 ins.	50 ins.
Peripheral vel. per min.	2,712 ft.	3,080 ft.	3,505 ft.	2,487 ft.
Peripheral vel. per sec.	45 ft.	51 ft.	58 ft.	41·5 ft.
Diam. of Suction	2 of 24 ins.	4 of 17 1/2 ins.	2-24 ins.	20 ins.

PRINCIPAL FEATURES OF SOME OF THE DREDGE BOATS OPERATING ON THE MISSISSIPPI RIVER BELOW ST. LOUIS.—(*contd.*)

	GAMMA.	DELTA.	EPSILON.	Maj. HANDBURY'S No. 4.
Width Suction mouth	19 ft.	33 ft. 6 ins.	20 ft.	10 ft.
Max. depth suction works	16 ft.	16 ft.	16 ft.	15 ft.
Diam. of Discharge	34 ins.	34 ins.	32 ins.	24 ins.
Nom. cap. sand per hour	800 cu. yds.	800 cu. yds.	1,000 cu. yds.	1,000 cu. yds.
Ave. barge tests sand per hour 1897,(*a*)	1,523 cu. yds.	1,850 cu. yds.	2,553 „ „	.....
Ave. of 1898 continuous still water tests, (*b*)	1,008 „ „	1,259 „ „	1,305 „ „	.....
Sand per hr. per I. H. P. in (*a*)	3·28 cu. yds.	1·62 cu. yds.	3·38 cu. yds.	.....
„ „ „ „ „ (*b*)	2·12 „ „	1·26 „ „	2·00 „ „	.....
SAND AGITATORS.				
Type	Water Jet	Mechanical	Water Jet	Water Jet.
Type of Pump	Centrifugal	None	Centrifugal	Worthington Compound Duplex Non-Condensing Plunger.
Size	18 ins.	.....	15 ins.	12 ins. Plungers.
Diam. & stroke of engine	12 & 22 × 14 in.	12 1/4 & 12 1/4 × 15 in.	12 & 22 × 12 in.	8 & 12 × 10-in. stroke.
Number of jets	9	.....	10	2 of 3 each.
Diam. of jets	2 1/4	.....	3 ins.	1 1/2 in.
Pressure	14 lbs.	.....	14 lbs.	65 lbs.
ELECTRIC LIGHT PLANT.				
Type of engine	Horizontal Belt	Vertical Belt	Horizontal Direct	Single Cylinder Aut. Cut-off 25 H. P.
Diam. of Cylinder	8 ins.	7 ins.	5 ins.	7 ins.
Stroke	10 ins.	9 ins.	6 ins.	10 ins.
Type of Generator	4 pole	4 pole	4 pole	Multipolar direct current, Constant Potential 110 volts.

Capacity	12 K. W.	9 K. W.	12 K. W.	9 K. W. at 850 rev. per minute.
Search lights	1	1	1	1 of 4,000 c. p.
Arc lights	4	2	2	2 of 2,000 c. p.
Incandescent lights	75	100	75	75 of 16 c. p.
BOILERS.				
Number	6	4	6	2 of 000.
Type	Mississippi River	Heine Water Tube	Mississippi River	Mississippi River.
Diameter	48 ins.	.....	48 ins.	48 ins.
Length	28 ft.	.....	28 ft.	28 ft.
Tubes or flues	5	140	3 & 2	5 flues.
Tubes diameter	11 inches	3 1/2 ins.	11 & 13 ins.	11 ins.
Tubes length	28 ft.	16 ft.	28 ft.	28 ft.
Total heating surface (*c*)	2,572 sq. ft.	8,184 sq. ft.	3,000 sq. ft.	3,780 sq. ft. for 6 boilers.
Total grate surface (*d*)	137 1/2 sq. ft.	213 sq. ft.	143 sq. ft.	108 sq. ft.
Ratio of (*c*) & (*d*)	18·7	38·3	21	35.
CREWS.				
On dredge	44	44	44	46 for double crew.
On large tender	26	26	26	Not in regular attendance.
On small tender	16	16	16	4.
On pile sinker	7	7	7	Taken from dredge.
GENERAL.				
Contractors	J. S. George and Howard P. Eells, Receivers, Bucyrus S. S. & D. Co.	New York Dredging Co., Geo. W. Catt, Prest.	Springfield Boiler & Manfg. Co., C. C. Brown, Prest.	Several: Pumps by Edwards, Engines Bucyrus Co.
Contract price	$85, 530·60	$124, 940·00	$102, 000·00	$102, 000·00
Final cost	.....	.....	.....	$111, 000·00 *
When completed	August 1897.	August 1897.	March 1898	1897.

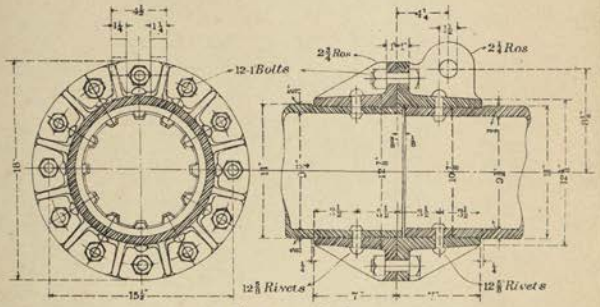
* Includes the cost of 1,000 feet of 24" discharge pipe and improved pontoons.

HYDRAULIC PILES.

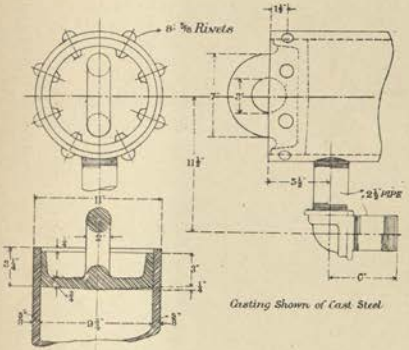
In the early operations of the dredge committee with their experimental dredge it was found advisable to use special hydraulic piles. In operating the dredge, two such piles are set about 25 feet apart near the upper end of the cut to be excavated. A wire rope about 1,000 feet long is attached to each of them and to the hauling drums on the dredge. "If the wind does not deflect the dredge from its proper place, it is allowed to swing freely in the current with the discharge pipes trailing below it. If necessary, side piles are set, and by means of lines attached to them, the dredge can be hauled into such position as may be desired. In dredging, the boat is pulled ahead upstream at rates varying with the depth of the material taken out, the average movement being about 60 to 75 feet per hour. After one cut is finished, the dredge is dropped down again to the lower end of the bar, the head piles are moved over about the width of the cut, and another cut is made near by and parallel to the first. This process is repeated until a channel of the required width and depth has been secured."

Mr. Ockerson says, "There is perhaps no single feature which facilitates this matter of dredging as much as the hydraulic mooring piles (see plate). The ease with which they can be set and withdrawn, and their great holding power make them really indispensable where dredging is done in strong currents. They are sunk 15 or 20 feet deep in the sand, and the head lines are attached to a shackle down at the surface of the sand and consequently there is little danger of bending. A pile sinker provided with suitable leads and hoist, pumps and boilers, is required with each dredge. The pile is open at the lower end for the full size of the pipe. On the side of the pipe near the upper end is an opening $2\frac{1}{2}$ inches in diameter to which the pressure pipe from the pump is attached. The ease with which piles can be set and withdrawn is shown by results of experiments quoted below. In these experiments a 6-inch double plunger pump was used. The length of the piles was $34\frac{1}{2}$ feet, outside diameter 11 inches, thickness $\frac{3}{4}$ inch for the heavy piles, $\frac{1}{2}$ inch for the light piles; weights respectively 3,250 lbs. and 2,370 lbs. each. In eleven tests made, in depth of water from $2\frac{1}{2}$ to 12 feet, with penetration of

DETAILS OF HYDRAULIC ANCHOR PILE



Connection Shown of Cast Steel



Casting Shown of Cast Steel

General View of the Pile

piles of from 18 to 20 feet, the pressure required varied from 30 to 55lbs. The time required to sink the piles varied from 3 minutes 23 seconds to 6 minutes in all but one case where $8\frac{1}{2}$ minutes was required. The piles were then left undisturbed for different periods of time varying from $\frac{1}{4}$ hour to 16 hours, when they were raised. The time required for raising varied from one minute 5 seconds, to 1 minute 58 seconds. The boiler pressure used was from 60 to 80 lbs. In six of the tests the hoist only was used to draw the piles, while in the remaining five the hoist was assisted by the pump.

DREDGE CAPACITY TESTS MADE IN 1898.

SPECIAL capacity tests of the dredges were made in the latter part of 1898, and the following information has been extracted from a report thereon submitted to the Secretary of the Commission by Mr. Maltby, Assistant Engineer in charge of the dredging operations.

In the first tests made at the time of taking over the dredges from the contractors, the measurement of the material moved was done by deflecting the discharge for a short interval of time into a measuring barge. "This time interval was so short, averaging perhaps a little over a minute, that a small error in reading time would seriously affect the computed capacity per hour. This method is open to the more serious objection that the determination of quantity of material being discharged is based upon the assumption that the conditions existing at that particular time are continuous, which hardly seems warranted from experience in dredging operations."

In the tests lately made, the object was to arrive at the capacities of the dredges by operating in water without current, which admits of measurements of the quantity moved being determined by surveys before and immediately after the conclusion of the test. The places chosen for testing were in pools or back waters free from current. The dredges were placed in position and worked continuously with slight interruptions for repairs, until completion of the test.

Gamma.

The Gamma excavated eight cuts aggregating 4,566 feet in length during 45 hours and 30 minutes actual dredging. The material moved was chiefly fine sand with a small quantity of blue mud. The total volume moved, as calculated from surveys of the bottom, was 45,856 cubic yards, or at a rate of 1,008 cubic yards per hour. An experiment was also made to determine the practicability of cutting into a sand bar above water. "With suction lowered to 12 feet the dredge began to pull into the dry bar and after working one hour and 50 minutes, had cut into the bar a distance of 45 feet. This test was then discontinued on account of the very large amount of small drift encountered buried in the sand, it having been demonstrated that the dredge could penetrate the dry bar. At the point where the dredge entered, the bar was bluff and 2 feet

above the water surface; the height of bar increased to about 4 feet above the water at the bow of the dredge when the test was concluded."

Delta. The Delta made four cuts, aggregating 2,711 feet in length, in a time of actual dredging of 27 hours and 23 minutes. The quantity of material moved was 34,365 cubic yards, measured from cross sections 50 feet apart, taken before and after the test, and checked by measuring with a planimeter the contour areas within the dredged area, before and after dredging. The average moved per hour was 1,259 cubic yards, but on cut No. 4 where the dredge was kept well pulled up to her work it was 2,550 cubic yards. Mr. Maltby remarks that the capacity of the dredge seems to be limited only to the ability of the pontoons to carry the dredged material away.

Epsilon. The Epsilon made four cuts, having a total length of 2,015 feet in time of actual dredging of 24 hours and 50 minutes. The material moved was computed from cross sections at 32,407 cubic yards or 1,305 cubic yards per hour.

Zeta. The primary purpose of the test of the Zeta was to determine the practicability of dredging through a dry bar, and the secondary to measure the capacity of the dredge. At the point selected the bar was bluff and about 4 feet above the water surface. "The head cables were attached to deadmen placed on the dry bar and anchors were set out on either side of the dredge on the bar and side lines made fast to them. The test was begun at 2-20 P.M., November 3rd, and continued till 4 P.M. November 6th, when, after 62 hours and 55 minutes actual dredging, six cuts had been made, having a total length of 1,785 feet. For the purpose of demonstrating the feasibility of cutting across a dry bar the test was entirely successful. A hole was cut in the dry bar approximately 500 feet long, 140 feet wide at top and having a depth of from $3\frac{1}{2}$ to 4 feet above water and 13 feet below water, along the axis of cuts, the sides under water standing at a considerable angle to the vertical."

The capacity test is not considered a fair one for this dredge on channel bars where the conditions are so different. (Nor was it intended as such.) The total volume moved was 40,991 cubic yards, a rate of only 652 cubic yards per hour, due largely to the character of the material encountered. The composition of the bar above water and

to a depth of about 7 feet below the water surface was pure sand, but beneath this was a layer of blue clay. Had the suction been raised sufficiently high to clear the clay, a higher capacity would have been obtained. The following tabulated statement shows in a condensed form, convenient for comparison, the results of the several tests:—

CONSOLIDATED STATEMENT OF DREDGE TESTS.

	"Gamma."	"Delta."	"Epsilon."	"Zeta."
Extreme width of suction in feet ...	19·0	33·6	20·3	20·3
Number of cuts made	8	4	4	6
Total length of cuts in feet ...	4,566	2,711	2,015	1,785
Time actually dredging, hours ...	45·50	27·38	24·83	62·92
Average advance per hour in feet ...	100·3	99·0	81·0	28·4
Average depth of suction below water surface in feet	15	13·6	17·0	17·0
Average depth of cut in feet ...	7·16	6·55	9·6	20·6
Average steam pressure	145·6	151·1	130·0	146·8
Average speed of main pump, revolutions per minute	150	140·9	178·0	179·0
Suction head, main pump, in feet of water	8·9	16·3	9·5	10·3
Delivery head, in feet of water ...	8·0	34·2	34·6	19·9
Jet discharge head, in feet of water...	23·6	.....	25·1	24·9
Total No. cubic yards moved ...	45,856	34,462	32,407	40,991
Average No. cubic yards per hour ...	1,008	1,259	1,305	652
Cost per lineal foot for time actually dredging	$0·0898	$0·0926	$0·142	$0·307
Cost per cubic yard for time actually dredging	$0.0089	$0.0073	$0·0092	$0·0134
Length of discharge pipe, feet ...	750	1,000	1,000	250 to 600

GENERAL REMARKS AND COMPARISON OF DREDGES.

It may now be useful to consider some of the special features of the different dredges. For the purpose of these notes, the Beta is put aside as too ponderous and on too magnificent a scale for use on the Indus River. Its short time tests gave an average capacity of as much as 4,920 cubic yards per hour, a marvellous result, but the original cost of the Beta was over $200,000, and considerable sums have since been spent in lessening the draft, re-arranging the hoisting and spud machinery, &c., which have brought up the total cost to over $250,000.

The Alpha and Major Handbury's Nos. 1 and 2 were experimental dredges and may be omitted. The Zeta has been provided with jets as agitators instead of mechanical cutters, and is now similar to the Epsilon; thus the enquiry into the relative merits of dredges of nominal capacity of from 800 to 1,000 cubic yards per hour is limited to consideration of the Gamma, Delta, Epsilon, and Major Handbury's No. 4.

All four meet the requirements as far as the machines themselves are concerned. Their value as aids to navigation depends largely on the location of the dredged cut across the bar, but consideration of this point may be neglected at present as the special object of this inquiry is, if possible, to fix on a suitable design for a dredge to keep open "dhands" or chutes and the approach channels to canal heads on the Indus River. All four dredges are good, practical, working machines which have been in commission for two working seasons; but, having been built at or about the same time, they are not necessarily developments of each other, and in some feature each is more or less experimental.

Comparison of Efficiency.

To compare efficiency of the dredges it is first necessary to decide how it is to be arrived at, and then, if possible, to determine to what particular feature of each the difference in efficiency is due. In the present state of knowledge on the subject this is a very difficult problem. The first serious difficulty is that of obtaining a correct measure of the work done by the dredge. Opinions differ as to the amount of reliance which can be placed on the short time tests and on the measurements

of the continuous work tests in still water. The writer does not propose to discuss the merits of these tests, but may state that in his opinion the test of a machine of this description should approach as closely as possible the working conditions, that is, it should require continuous work for several days and the aggregate material moved should be measured to obtain a correct average per hour of the capacity of the pump. The requirements demand a "stayer," not a "sprinter." If the discharge could be delivered into an enclosed space on dry ground and the solid material be measured after the water has drained off, the correct average capacity would be given with little chance of error; but there are practical difficulties in arranging such a delivery as the dredge moves forward on its cut and, in the first place, in finding a suitable locality for such operations.

While there is difference of opinion on the amount of reliance to be placed on the tests made, much weight should not, perhaps, be placed on deductions from them. Still, they must give some indications of the work done, they are not so unreliable as to be worthless, and the writer proposes to use them for general conclusions.

Referring to the tabulated statement of features of the dredges, it will be seen that the Gamma compares very favourably with both the Delta and the Epsilon in many respects. (Unfortunately there is no record of tests for Major Handbury's dredges.) Its capacity, sand per hour per indicated H.P., in the still water continuous tests of 1898, was 2·12 cubic yards, the best obtained that year, and in the barge tests of 1897 it was as high as 3·28. It is true that the Gamma was working in the former tests with a shorter discharge pipe than either the Delta or the Epsilon, but the Zeta, with a still shorter pipe, showed considerably less capacity in its test, and the question as to whether the conditions in which the Zeta was working were unfavourable to discharge, as claimed by some, is quite an open one. The cost per cubic yard of the outturn is cheapest with the Gamma, and the speed of its pump is considerably less than that of the Epsilon, a decided recommendation for a sand pump in which heavy wear must be expected. The Gamma is the smallest and most easily managed, its hauling ahead and suction head gear and the spud lifting arrangements are simple and efficient; finally, its first cost was less than that of any of the others. It may therefore be

concluded that the Gamma is one of the most efficient dredges on the river, and in at least some respects is worth taking as a model for a large dredge on the Indus.

The writer has had the advantage of discussing the different features of the several dredges with the engineers responsible for their construction, and has also quite lately inspected the Mississippi Commission Dredges in their winter quarters at Memphis, where he saw the different pumps opened out for inspection and repair after their season's work. The amount and character of the wear shown in the several pumps, particularly in that of the Gamma, seems to have caused general surprise. This, however, can be provided against by suitable linings.

Variety of Design.

Beginning at the suction head, there has been considerable variation in design and, at first, an absence of knowledge as to whether jets or mechanical agitators were preferable to loosen up the sand in front of the suction head. There is no doubt now that in ordinary circumstances, where nothing harder than silt or sand is to be dredged, an arrangement of hydraulic jets along the front of the suction amply meets the requirement, is much more simple and uses less power than any mechanical agitator yet devised. As regards the shape of the suction head itself, while all are broadened out to take a good width of cut, they vary in height from only a few inches in the case of the Beta to as much as two and-a-half feet on the Epsilon and Zeta (the sectional area being reduced by vertical lobes, as shown on the view of the Epsilon suction head).

The Gamma and Epsilon have double suction pumps, the two suction pipes leading from one common head in each. The Delta has one single suction pipe, leading, however, from four smaller pipes connected with the head; while on Major Handbury's No. 4 there are two entirely separate plants, each pump having only one suction pipe leading from its suction head and each being independent of the other. The arrangement of the Delta is the most complicated; it involves greater sub-division of the suction pipe and a larger number of bends and would seem to be the least preferable in these respects.

Major Handbury is strongly in favour of the Edwards pump which has only one suction pipe entering it; the pump is undoubtedly

a good pattern and one in which the linings can easily be renewed. On the other hand, the double suction pump is not open to so much objection as might at first be thought; the diaphragm on the runner apparently fully meets the object of its design without showing particular signs of wear. Again, Major Handbury prefers to have the suction heads of his two pumps independent of each other but, though there may be some advantage in this arrangement on a dredge with two independent pumping plants, the writer is inclined to prefer a connected or continuous suction head for the two pipes of a double suction pump plant.

The number of blades, or wings, on the runners of the sand pumps seems to vary largely according to the fancy of the maker, from as few as three to as many as seven. Four or five at most appear best suited to the conditions. In some of the dredges the discharge pipe is depressed below the water-line, close to the pump, to assist in priming, but in Major Handbury's dredges a suitable priming valve is provided and is an improvement.

There is great variety in the relative proportions given the sectional areas of the suction and discharge pipes on the several pumps. On the Gamma the combined suction nearly equals the discharge area. On the Delta and Epsilon they are 962 and 908 square inches respectively, while on Major Handbury's dredge they are 628 and 904 square inches respectively. One apparently objectionable feature in the double suction pump is the presence of the pump shaft in the bend of the suction pipe as it approaches the pump itself. The writer believes efficiency of a pump depends largely not only on freedom from bends and obstructions to discharge, but also upon the proportions given the suction and discharge pipes. Some makers do not, however, admit this to be the case, but contend that within certain limits a small variation of velocity of flow makes no appreciable difference. It is stated in correspondence with the writer that "many pumps that largely violate these considerations still do efficient work." The writer would reply, were the conditions not violated the pumps would probably do more efficient work.

Of the different arrangements for manipulating the spud, that adopted on the Gamma is the simplest. The anchor spud is hoisted by means of an upright single acting steam cylinder, the piston of which is attached to a cam clamp at its upper end which grips and holds the

spud against the slides. In the alterations lately made to the Beta this arrangement has been applied, indicating the approval of the Commission of this method of handling the spud in preference to others tried.

Of various forms of pontoon pipes, those used on Major Handbury's dredges are perhaps the best suited for the requirements; the great desideratum is sufficient floatation to carry the pipes when loaded entirely with sand.

When first considering the question of a large dredge for the Indus river, the writer was inclined to think it a necessary condition that the dredge should be self-propelling, but on finding that on the whole Mississippi river there were only two such dredges, the Ram, a comparatively small one, and the Bailey which discharges into bins, he found it necessary to follow in the footsteps of the Commission and to study the conditions prevailing and the methods adopted to meet them. Then, as he became familiar with the details of the large dredges lately built, he was inclined to the conclusion that for the conditions of the Mississippi, where large tow-boats are obtained without great difficulty, the barge or non-self-propelling dredge is well adapted for the work it is called upon to perform, though it is an open question whether this would be true of the Indus. So long as the dredges were considered experimental, the Commission seem to have been satisfied to have them non-propelling. They are, however, at the present time building a self-propelling dredge of large capacity, but the writer has not obtained any detail of it as he believes the information given in the foregoing pages concerning large dredges will meet the present requirements and that, if later on information is wanted concerning the large self-propelling dredge, it can most usefully be obtained after the results of her trial are known.

While there may be doubt as to whether large dredges should be self-propelling, the writer is decidedly of opinion that small dredges, of a capacity of from 300 to 400 cubic yards per hour, can certainly be made self-propelling with advantage, especially when they are intended for use on such duty as the keeping open of canal mouths and other light work necessitating frequent shifts. Light dredges of this character are dealt with further on.

PRELIMINARY SPECIFICATION FOR LARGE DREDGE INDUS.

THE following brief specification for the Large Dredge Indus indicates the requirements and particular features advisable for adoption in the design of a dredge for the Indus River of capacity of 800 cubic yards per hour. The fixing of this figure does not mean that this capacity is necessarily required on the Indus; it is adopted merely for convenience, as a standard for the guidance of the dredge-builders who will be consulted regarding the design and the assemblage of the different parts of the machine.

It is proposed to make this dredge something after the pattern of the Mississippi Dredge Gamma, excepting in such features as are mentioned below.

Hull.—The hull should be constructed of steel, of from 125 to 140 feet in length, 35 to 40 feet in breadth, and 6 to 6 feet 6 inches in depth.

Cabin accommodation should be provided for the Superintendent, four engineers and officers, and an extra state-room and sitting-room for the Assistant Conservator in charge of dredge operations. Accommodation for a crew of thirty men should be separately provided. The dredge is intended for use on the Indus River, where the temperature varies from 95 to 115 F. in the shade, and the accommodation should be suitable for that climate.

Draft.—The draft should be kept as little as possible within the above limitations regarding size of hull; in no case should it exceed 40 inches; if necessary to obtain this, the hull must be enlarged.

Main Pump.—The main pump should have two suction pipes and one common delivery pipe, and be capable of discharging 800 cubic yards of sand per hour through 600 feet of the delivery pipe. The pump casing should be lined throughout with steel, in plates so arranged as to admit of the renewal of any or all of them without difficulty. The wings of the runner should also be protected with steel plates which should be turned down over the sides and ends and fixed with counter-sunk bolts in such a manner as to be renewable. The suction head is to be designed to work at any level between the surface of the water and a depth of 13 feet

below and the pump should be capable of delivering the 800 cubic yard per hour when the dredge is working at this latter depth.

Suction and Delivery Pipes.—The material to be dredged is recently deposited sand, silt and mud, and if a velocity of 10 feet per second in a discharge pipe will carry 12½ per cent. of sand, a 30-inch delivery pipe will suffice. With such a discharge pipe, two 20-inch suction pipes will probably meet the requirement of the pump, with, however, a slightly enlarged section at the elbows approaching the pump, to avoid undue loss of area where the pump shaft crosses the inflow. The builders are not to be limited to these dimensions, but their consideration should be requested to the relative sections and areas indicated and to the necessity for properly proportioning the areas of the water passages to maintain a regular flow and to avoid wear due to the impinging of sand at points where changes in direction of flow occur.

Speed of Pumps, &c.—The number of revolutions per minute of the engine and pump should not exceed 145. The peripheral velocity of the pump runner should not exceed 45 feet per second.

Suction Head and Jet Pumps.—The suction head should have a width of about 18 feet and be provided with an hydraulic pressure chamber and jets to loosen up the material. The jet pumps should be of the centrifugal type designed to give a pressure of 14 pounds per square inch. Five or six jets of from 1½ to 2 inches in diameter will suffice in the whole width of the suction head for the material on which these dredges will work.

Main Engines.—The main engines should be of the latest design suitable for the requirements, and be subject to the limitation that the revolutions per minute should not exceed 145 and steam pressure should not exceed 130 pounds.

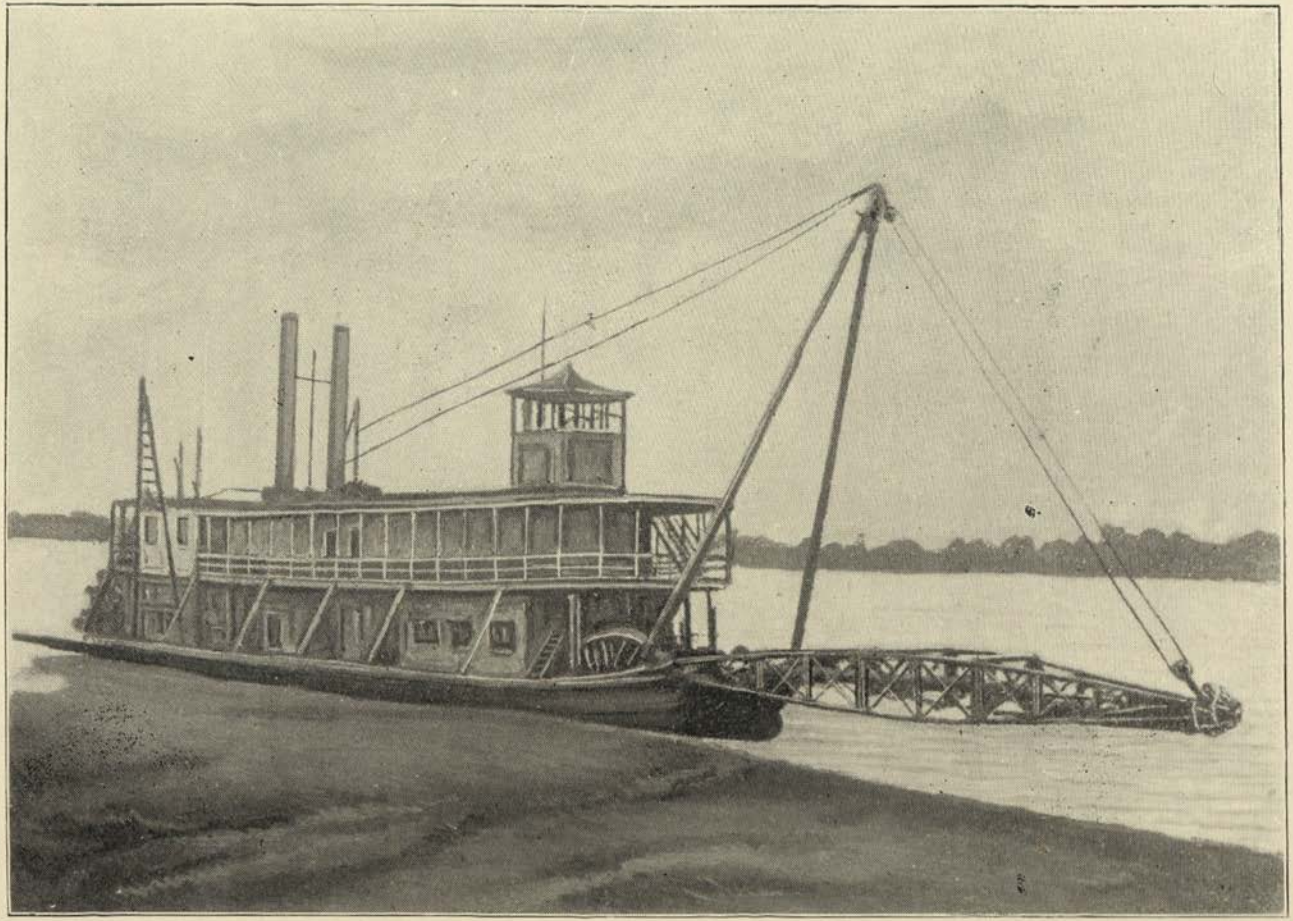
Electric Light Plant, Boilers, &c.—The electric light installation should provide for one search-light, two arc-lights, each of 2,000 c.p. and 75 incandescent lights each of 16 c.p. The boilers should be of an approved river-steamer type, the grate surface being arranged to burn either coal or wood.

Pontoons.—The discharge pipe pontoons should provide sufficient buoyancy to float the pipe line when loaded with wet sand, so that there may be no fear of the pipe sinking if, by accident, when pumping, it should become overloaded. These pontoons should be

rhomboidal in plan and arranged to carry the pipe on a centre swivel to admit of the pontoons swinging to the current, something after the method devised by Major Handbury for his dredges. The discharge pipe should be fitted at its end with a baffle plate for the purpose of steadying the pipe line while the material is being pumped through it.

Dredge Outfit.—The dredge outfit should include the necessary steel hydraulic leading piles and hydraulic pile sinker required for the anchoring and manipulation of the dredge.

General.—The dredge should be complete in all respects, and be supplied with all appurtenances provided on the Gamma.



U. S. Dredging Steamer Ram. Mississippi River.

SELF-PROPELLING DREDGES.

Dredge Ram.

THE Dredge Ram was built by the Bucyrus Steam Shovel and Dredge Co. in 1893 for use on the channel from the Mississippi river into the Red and Atchafalaya rivers. She was built under the direction of Captain John Millis, Corps of Engineers, and cost $69,500. Her capacity is about 300 cubic yards of mud per hour delivered through 300 feet of pipe. Mr. Wooley, Assistant Engineer, in the discussion on Mr. Ockerson's paper on dredges, states that the material handled under working conditions averages about 150 cubic yards per hour, taking a test lasting over a period of 4½ days, on a reef of compact fine sand. "This dredge has handled material for 2½ cents per cubic yard." . . . . "This dredge has proven to be an exceedingly satisfactory machine, all things considered. The most serious objection that could be raised is to the wooden hull, and the small dimensions for carrying so much machinery, together with the supplies of lines, etc., that are needed for a season's work."

Mr. Wooley briefly describes the Ram and method of working her as follows :

The hull is of the decked barge type, 95 feet long, 27 feet beam, 6 feet 6 inches deep ; the propelling engines are of the modern high pressure western river type connected to the usual stern wheel ; the suction pump is a 15-inch Edwards centrifugal, with a 3-winged runner, and intake in the starboard axis of pump ; the discharge is from the bottom of the casing through the rear to a pipe suspended below deck to a " Y " near after end of the boat and just forward of the spud ; it is diverted to port or starboard at will by the "Y" ; the out-board discharge is connected to a floating pipe line or to a short section (55 feet), suspended by shear legs directly from the side of the boat ; the pump suction is carried by the cutter frame to the base of the cutter head ; the cutter head is supported at the forward end of the cutter frame, and is driven by a 5-inch shaft, made in three sections, connected by claw couplings, all supported by bearings on the cutter frame and driven by high pressure engines and sprocket gearing on the bow of boat ; the cutter shaft is connected to sprocket gearing by mitre wheels directly on the bow of the boat, to permit of the cutter frame being raised or lowered through a large vertical arc ; the cutter frame has a triangular horizontal section, its base being hinged to the bow of boat and its apex or forward end suspended by wire rope tackle from an A-frame slightly overhanging the bow, the suspending

tackle is connected to hoisting engines on the forward deck for raising and lowering the cutter to the desired depth ; the swinging chain and cables lead from friction drums on the bow of boat through the cutter frame near the forward end to anchors or deadmen on either side of channel ; the spud is on the axis of the hull 10 feet from the after end, and by means of the swinging cables the cutter is swung back and forth across the channel to be cut, with the spud as a centre and the distance between spud and cutter as a radius.

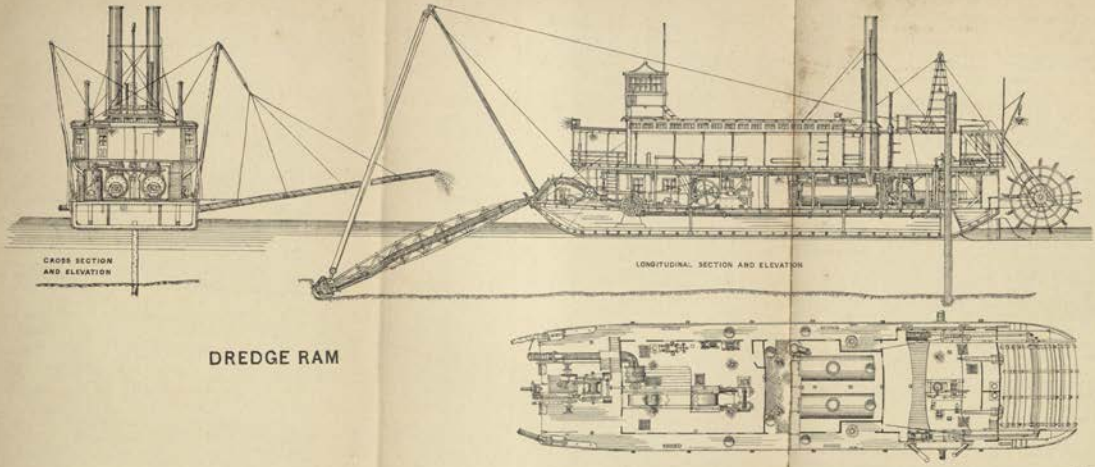
For the work in the Old River, with the strong current which usually prevails, it was found very difficult to use the pontoons. It was then decided to suspend as great a length of discharge pipe as possible from the side of the boat and discharge directly overboard. By keeping the dredge well to the side of the channel on which the discharge was being placed, taking the full swing in the opposite direction, it was found that the material could be placed 60 feet away or on top of the flat shelf outside of the dredge channel. . . . . It was found that a very small percentage of discharge returned to the channel. The ease of manipulation much more than outweighed the return of material to the cut, as compared with the stoppage and loss of time due to buckling and fouling of the pontoon line in shallow water. . . . .

In cutting through a dry bar, the cutter head is lowered to the desired depth of channel and worked forward just as fast as the material sloughs down the face of the cuts. . . . .

From the foregoing, it will be evident that the depth of the single cuts within certain limits has to be determined by the class of material being handled. The dredge is always worked downstream, and the greater the velocity of the current, the greater the necessity for so doing to prevent the fouling of the channel behind the dredge. (This working down stream would be the condition in which dredges would probably be used on the mouths of canals of the Indus river. As a matter of fact, however, the Mississippi river dredges are usually worked upstream). And when dredging in pure sand, the depth of clear channel behind the dredge and the depth of the cutter head varies from 9 to 18 inches. . . . The Ram was fitted and designed to work with a walking or push spud to be operated by steam, but this arrangement was not successful. The spud is now used only to hold the dredge in place : when it is raised the dredge is fed forward by the propelling engine.

Under ordinary working conditions and depth of cut, the cutter head is swung across and back again over the desired width of cut. The spud is raised and the dredge forced forward by the propelling engines. The usual forward movement is from 18 to 24 inches each time and at about four or five minutes' interval.

After four years' experience with this particular dredge, Mr. Wooley is of the opinion that a machine of this type, which can devote 75% of its working time to actual dredging, is quite up to, if not above, the average. . . . The cutter head has proved to be amply strong for all kinds of work. Many piles, sunken


CROSS SECTION
AND ELEVATION
LONGITUDINAL SECTION AND ELEVATION
SECTIONAL PLAN

DREDGE RAM

saw logs ..... have been encountered and disposed of, and not a single blade on the cutter has been broken. ..... For the various classes of material, from stiff clay to sand, and including all kind of *débris*, the present design of cutter head is well adapted. The 15-inch Edwards' pump has given great satisfaction, is comparatively easy of repair, has worn extremely well, and is admirably adapted to this kind of work.

There is but one slight objection to the details of this pump: for the high speed required, Mr. Woolley has found need for larger thrust bearings. With some minor alterations and with water jets, he has been enabled to run the pump at 260 revolutions per minute for eleven consecutive hours, without undue heating. The engines were built by the Bucyrus Co. after their own pattern with high pressure cylinder 14½ × 20 inches and low pressure cylinder 26 × 20 inches, placed on a rigid hollow girder bed frame. The engines are driven at 130 revolutions per minute and develop under ordinary working conditions with 100lbs boiler pressure from 170 to 190 H. P. The engine and pump are connected by belt; the revolutions of pump and engines have a ratio of 2 to 1 ..... The present wooden hull has proven entirely too small for the convenient manipulation of the machinery. ..... The new steel hull will be 25 feet longer, and will contain ballast tanks on either side to enable a greater length of discharge pipe to be suspended from the side of the boat, and at the same time to allow the boat to work on an even keel.

The propelling engines are capable of driving the dredge and a tow, consisting of a large fuel barge as well as all pontoons and other necessary equipment, upstream at the rate of 6 miles per hour.

The writer's attention was early directed to this dredge as probably the best suited for the requirements of the Indus Canal mouths. He therefore made a special visit to her at New Orleans, and obtained blue print copies of plans of the dredge. A detailed description of her will be found in the specification written by Captain John Millis, at page 2979 of the Chief of Engineer's Report for 1894, of which extracts are given below for convenience of reference.

The "Ram" is a self-propelling dredge of the suction type. Her hull is 95 feet long, 27 feet wide, 7½ feet deep, built of pine, with bulkheads dividing her into water-tight compartments. The hull is stiffened with hog chains and bracing.

The house is double-decked, extending nearly the full length of the dredge, entirely covering in the whole of the machinery. The upper deck provides accommodation for the crew.

Ample provision is made for coal bunkers and steering gear.

The spud is of timber 18 inches square, with steam cylinder raising arrangement and of sufficient length to hold the dredge when operating in 30 feet of water. This spud is the pivot upon which the dredge swings when in work. The main boilers are of the horizontal tubular type. Each boiler is of steel

16 feet long, 60 inches in diameter, adapted to regular working pressure of 120lbs. per square inch. There are 74 3-inch tubes, steam dome 30 inches in diameter by 30 inches in height rivetted to the boiler shell. The chimneys are 30 inches in diameter and 35 feet long, with metal jacket 42 inches in diameter for that portion of the length between decks. An auxiliary boiler of the vertical tubular type is provided, 40 inches in diameter and 6 feet high.

The main driving engine is compound condensing horizontal type, stroke 20 inches, high pressure cylinder 14½ inches diameter, low pressure 26 inches in diameter, bed frames of hollow girder pattern with main bearings for crank shaft cast on. The bearings are fitted with phosphor bronze linings adapted to adjustment for taking up wear. The crank shaft is of steel 5 inches in diameter, fitted with balance crank discs, &c. The main cutter shaft and winding drums for hoisting the cutter and swinging the dredge are operated by a pair of auxiliary engines placed forward on the main deck. The operating handles for clutches and throttle valves of the auxiliary engines are placed so that the engineer from his station on the forward deck near the auxiliary engine has a complete oversight and control of the operation of the dredge.

The cutter is supported at the apex of a strong timber and iron frame projecting from the bow of the boat. It is hinged at the bow and of sufficient length to enable the dredge to work effectively in 30 feet of water. It also enables the dredge to dig her way when there is not sufficient depth to float her.

The cutter consists of a conical steel casting to which eight crucible cast steel cutter blades are securely bolted, forming a conical cutter head about 4½ feet in diameter at the base and 2 feet in diameter at the outer end. The cutter blades are ¾ inch thick with strengthening ribs. The cutter is carried on a steel shaft 5 inches in diameter, &c.

The main suction pump is a centrifugal of the Edwards' pattern, with suction and discharge openings 15 inches in diameter, mounted on C. I. bed frame and lined with renewable cast-iron plates. The wings of the pump runner are renewable steel plates. The top of the casing can be removed without difficulty and the lining pieces be replaced in a very short time. (The foreman in charge of the boat informed the writer that there was no difficulty experienced on account of the wear of these plates because of the facility in replacing them when necessary.) The suction and discharge pipes are 15 inches diameter, provided with flexible suction hose and couplings as indicated on the plan. Outside the hull the discharge pipe is welded steel, 16 inches inside diameter.

Review.

These extracts assist considerably in enabling one to arrive at a correct idea of the efficiency of the Ram. It must be remembered that she was built in 1893, when hydraulic dredges were a comparative novelty. With slight alterations and improvements, as would be made in the current day, a dredge of her description would undoubtedly do good work. The alternative

of side discharge or stern delivery is a decided advantage on a small dredge intended for the deepening of approaches to canals taking off from a river. In fact, experiments with a side delivery pipe from 100 to 200 feet long instead of a stern floating pipe have been suggested for the large Mississippi dredges, as it is recognized that the side delivery, if applicable, has many advantages over the stern delivery, and it is argued that there is generally an up-stream and down-stream side to the artificial channel cut, "and it appears that if the excavated material could be delivered on the down-stream side, it would either be taken away from the cut by the current, or, if it remained where deposited, would act as a training dike, and serve to increase the natural scour in the channel. The saving would be in the increased output with the less friction in the shorter pipe."

SMALL DREDGE INDUS.

THE writer considers side delivery an essential on a light dredge for the Indus canal mouths, but he would also provide a small outfit of pontoon pipes for discharge astern. The side delivery should be to a distance of at least 100 feet from the side of the dredge. This adds slightly to the difficulty of design, as it necessitates provision for tanks to serve as counter-weights on both sides of the boat so that the discharge may be delivered at either side at pleasure and still keep the dredge on an even keel. This lengthening of the side delivery and its suspension, shear legs, &c., exaggerates the objection which the writer has to the general principle on which the Ram is worked, that is, of swinging on a spud in order to obtain an increased width of cut. The swinging motion is obviously also objectionable when discharging through stern pontoon pipes and, as experience has given great success with the hydraulic jet as an agitator, a simple solution of the difficulty is to provide a broad flat suction head with jets something after the design of those used on the larger dredges.

Specification for "Small dredge Indus."

The following preliminary specification indicates briefly the requirements of a light dredge for the Indus river.

General.—This dredge is intended for the purpose of keeping open the entrances or approach channels to the mouths of large canals taking off from the Indus river. She should be self-propelling and be capable of delivering 300 cubic yards per hour of sand, silt or mud (recent deposit, deposit of silt caused by fall in stage of the river in the early part of the flood season, or deposit of silt left on the falling stage of the river, at which time the supply of water in the canal or depth in channel of approach has to be maintained). The material is to be delivered through a pipe at the stern of the boat into a discharge pipe carried on pontoons of a total length of 300 feet, or to be delivered to either side of the dredged channel at a distance of 100 to 120 feet, at a height of 10 feet above water surface; the pipe, suspension shear legs, &c., for the side delivery being all provided and carried on the dredge itself.

Hull.—The hull should be of steel and about 100 to 115 feet in length, of beam and depth suitable to give a draft not exceeding 30 inches.

Engines.—The propelling engines should be of modern high pressure type, connected with either stern or side wheels, as preferred by the contractor.

Pump.—The pump should be capable of discharging 300 cubic yards of sand per hour through 300 feet length of delivery pipe. The peripheral velocity of the pump runner should not exceed 45 feet per second. The suction head should be provided with hydraulic jets, say six of $1\frac{1}{2}$-inch diameter, to agitate or loosen the material on which the suction is working and should be arranged to work at any depth up to 12 feet below the surface of the water. The width of the suction head should be about 16 feet.

The pumps should be directly connected with the engines, and the number of revolutions per minute should not exceed 140.

Electric Light Plant, &c.—The electric light installation should provide for two arc-lights and seventy-five incandescent lights.

The designs should provide for cabin accommodation for a Superintendent and four officers, and separate accommodation for a crew of ten men.

The outfit should include steel piles and pile sinker, if such are considered necessary for the working of this dredge.

The discharge pipe pontoons should provide sufficient buoyancy to float the pipe line when loaded with wet sand.

If it is necessary, when using the side delivery pipe, to apply a counter-balance on the other side of the boat to keep her on an even keel, water tanks should be provided for this purpose and to admit of delivering the material at either side of the boat as may be convenient.

APPENDIX A.

OFFICE OF THE SECRETARY, MISSISSIPPI RIVER COMMISSION,

ST. LOUIS, MO., *February* 28, 1899.

THE following general instructions are issued for the guidance of assistant engineers and others under the orders of this office.

MASON M. PATRICK,
Captain, Corps of Engineers,
Secretary, Mississippi River Commission.

SURVEY OF THE MISSISSIPPI RIVER.

The objects of the Survey of the Mississippi River are, to obtain sufficient data for an accurate topographical and hydrographical map which may be used in studying the physical characteristics of the river, planning improvements, and also serve as a basis for future surveys by means of which the changes in bed and banks may be ascertained, and their causes and effects studied. The importance of having the work accurately done and the information embodied therein reliable, is therefore apparent.

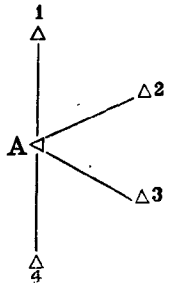
The experience gained in previous surveys, covering a period of many years suggests the following instructions relating to the scope of the work and the methods to be employed. Other points may present themselves as the work progresses and new difficulties are met with.

INSTRUCTIONS FOR SECONDARY TRIANGULATION.

Locating Stations.—In locating stations it is desirable to fix them at such points as will give good conditioned triangles. The smallest angle in any triangle should never be less than 30° and but few of these should be permitted to enter into the system. The triangles should lie in such a way that pointings can be made from any station to the stations immediately above and below on the same side of the river. That is, blind lines should always be avoided. Other things being equal stations should be set where they can be readily found and where they will not be liable to be disturbed.

Reading Angles.—The angles will be read with Troughton & Simms theodolites, Nos. 1 and 2, ten-inch limbs, having micrometers reading to seconds. The

instruments will be mounted firmly and protected from sun and wind when in use. The value of the angle will be determined by eight combined results read as follows:



The instrument being at A, carefully levelled and in good adjustment. With the vertical circle to the right, or telescope direct, and lower motion fixed, point successively to △ 1, 2, 3, 4, recording the readings of both micrometers for each pointing. This gives a positive result for each angle. Then point to △ 4, 3, 2, 1, and record readings as before. This gives a negative result for each angle. A mean of the two gives one combined result. The readings in a positive and negative direction will eliminate twist of station or instrument, provided the readings occupy but a short period of time during which the twist, if any, is uniform.

For the next combined result. The telescope will now be reversed, that is revolved through, leaving the pivots in the same wyes and the whole will be revolved 180° in azimuth. The vertical circle will then be on the left; the limb will be shifted 22½° and the stations will be read forward and back as before. The notes for this series will be headed "circle left." Reversing the telescope will eliminate errors of collimation, small level errors and inequality of pivots. Shifting the limb so as to read the angles at equal intervals around the circle will eliminate periodic errors and errors of graduation.

The same programme is followed until all the results are obtained, the limb being shifted and the telescope reversed after each combined result.

The micrometer should be adjusted so the run will be nearly zero. This should, however, be tested at the beginning of each day's work and entered in the note-book.

Closing Triangles.—The error in closing a triangle should rarely reach and never exceed six seconds and the average closure should be much below this. This will require great care in the centering of instruments and targets. A discrepancy of one-third of an inch will give an error of a second in a distance of one mile. The transparent cloth, phaseless target which has been especially designed for this service will be used, the size varying with the length of triangle sides.

Base Lines.—Base lines will be measured at intervals of about 20 triangles. This will be done with the 300-foot steel tape. The line should be carefully

staked out and its grade determined instrumentally. Supporting stakes will be driven at intervals of 30 feet. The stakes marking the extremities of each tape length will be firmly set and free from any disturbing influence due to tension of tape or otherwise. On these stakes, strips of zinc will be fastened and remain until the whole measurement is completed. The temperature of the tape will be determined by three thermometers placed near the ends and in the middle of the tape. They will be attached to suitable supports and placed with their bulbs near the tape when measurements are being taken. Observers must be careful to keep sufficiently far away so as not to affect the thermometers.

The tape will be suspended in hooks at intervals of 30 feet and attached in such a way that it may swing freely and eliminate friction as far as practicable. The tension of the tape will be kept uniform while measuring, by attaching a weight of 16lb. The extremity of each tape length will be marked on the zinc strip with a fine line and suitably designated. The preservation of these strips furnishes a ready means of comparison of each tape length at any future time.

The line should be measured two or more times with a discrepancy when reduced of not more than 1 in 250,000. This can readily be done if measurements are made on cloudy days or at night.

Observations for Azimuth.—The azimuth of each base line will be determined by observing, with a triangulation instrument, two closely circum-polar stars at elongation, on two different nights.

The instrument and light should preferably be at the extremities of the base or a triangle side. The following order of observing will be used :

1st.

Circle right.
Point to light.
Point to star and note time.
Read level direct and reversed.
Point to star and note time.
Point to light.

2nd.

Shift limb 45.°
Circle left.
Point to light.
Point to star and note time.
Read level direct and reversed.
Point to star and note time.
Point to light.

3rd.

Shift limb 45.°
Circle left.
Point to light.
Point to star and note time.
Read level direct and reversed.
Point to star and note time.
Point to light.

4th.

Shift limb 45.°
Circle right.
Point to light.
Point to star and note time.
Read level direct and reversed.
Point to star and note time.
Point to light.

In the above programme the readings on the striding level may be omitted, and for the second pointing to the star there may be substituted a pointing to the reflection of the star from the surface of mercury.

The programme will then be as follows :—

Circle right.
Point to light.
Point to star and note time.
Point to reflection of star and note time.
Point to light,
etc.

On the second night repeat this programme starting with a reading of limb 45° greater than the last reading of previous evening.

It will probably be found most convenient in these observations to use Polaris, Ursae Minoris, Ursae Minoris and 51 Cephei.

The time will be determined by observing the meridian passage of high and low stars.

Stone Line Benchmarks.—At intervals of about three miles along the river, lines of pipe and tile marks will be set for future surveys.

These lines will be numbered and located about as shown on maps of previous surveys on file in this office.

The marks nearest the river will be far enough back to be safe from erosion for many years ; the others will be half a mile further back.

In cases where the bluffs are near the river the rear marks may be omitted. The marks will preferably be placed at property corners, along public roads or on property lines, in places where they can be readily found and where they will not be liable to disturbance.

It is desirable to determine the azimuth and distance between the successive marks on the same line when practicable. The marks should also be as nearly in a line as the conditions of location above named will admit.

The marks will be connected directly with the secondary triangulation where practicable, by pointings from two or more secondary stations, three pointings from each station, and by pointings from the mark to be located to two stations that will give a fairly good triangle, three pointings to each station.

Where the points cannot be located directly from the secondary work, a tertiary system may be used, starting and closing on a secondary line or on a tertiary base. In this work the angles may be read with a good 10-second transit and the triangles should close within 15 seconds. A steel tape or chain may also be used where desirable in locating the point which is farthest from the river.

Cutting Timber.—Cutting timber to clear lines of sight or for material with which to build stations should be avoided as far as practicable. Where cutting is necessary a strict account must be kept of the number of trees cut, their size and kind of timber.

Descriptions of Stations.—A minute description of each station will be made and entered in a note-book kept for that purpose. This description will be complete for each station and will show what the geodetic point is, and how marked. Its location with reference to surrounding objects will be shown by an

accurate sketch giving azimuth and distance to bearing trees, houses or other prominent objects.

A similar record will also be kept of the stone line marks.

Vertical Angles.—Will be read at all stations. Pointings should be made with telescope direct and inverted.

The height of the instrument above the permanent triangulation marks will be measured with a tape line and the result will be recorded.

At convenient points the permanent triangulation marks will be connected by levels with the permanent benchmarks.

Field Computations and Reductions.—Will be made in detail of all azimuth work, base line measurements, triangle sides, elevations of stations, locations of stone line benchmarks, tertiary points and the L. M. Zs of all located points connected with the secondary triangulation.

The notes will be kept in the following form :

[Left hand page.]

At @..... , 189...

Objects.	Micrometer A.	Micrometer B.	Mean of micrometer readings.

[Right hand page.]

Observer.....

Recorder.....

Angle.	Mean Angle.	Time.	Remarks.

INSTRUCTIONS FOR PRECISE LEVELS.

Instruments.—The instruments used on this work are the Kern levels and rods similar to those used in the precise levels of Switzerland, and were made by J. Kern, of Aarau. The instrument, with tripod, weighs 22 pounds. It has three steel levelling screws, with enlarged spherical ends at bottom, which are held to the tripod head by clamps fitting over the spherical enlargements. The wye adjustment is by means of a thumbscrew of very fine thread, so that the last final centring of the bubble is made with this screw. The bubble tube is fixed in a striding metal case covered with wood, with brass ends fitting on the collars of the telescope. The bubble case has a glass cover and a mirror that may be raised to the angle of 45° and so reflect the bubble image to the eye of the observer at the eyepiece. The telescope clamps also hold the bubble case in position ; this is removed, however, when the instrument is carried. The telescope gives an inverted image. The telescope has three horizontal wires, all of which are read, and the mean taken as the reading of that sight. This also gives a stadia measurement of the distance.

The rods are three metres long, made of two pine boards with a T- shaped cross section, provided with an iron spur at bottom with a flat end, and a watch level by which to hold it vertical. They are graduated to centimetres, and are read by estimation to millimetres. No target is used except at river crossings.

Value of Level Divisions.—Before commencing operations, the constants of the instruments will be determined. The most important of these is the value of one division of the level tube. This can best be determined by means of a level trier. It can also be determined in the field as follows :—

Set up the instrument firmly, mounting it on a wooden post, if possible, or better still, on a stone pier. Set up a rod in its tripod at such a distance that it can be distinctly read through the telescope. The distance should be at least 50^m, or if the air is very still, 100^m, and should be carefully measured. Adjust the instrument carefully, taking such length of bubble in the level tube that its ends will be about the middle or tenth graduated line on each side. Direct the telescope to the rod, and by means of the elevation screw cause the bubble to run to near one end of the level. Carefully note the position of the three wires on the rod and the reading of the level. Now, by means of the elevation screw cause the bubble to run to near the other end of the tube and note the reading of the wires and bubble as before. One result for value of one division of level can then be obtained. This operation should be repeated ten times. The elevation of the rod should be changed occasionally between sets in order to avoid estimating the same part of the same centimetre on the rod. It will be sufficient to run the bubble five divisions each side of its central position.

If k = distance from instrument to rod, in millimetres,

d, d^1 = distance through which eye and object ends of bubble move when run from near eye end to near object end, $\frac{d + d^1}{2}$ = amount of displacement of bubble between two readings.

r, r^1 = corresponding means of three thread readings on rod, and

v = value of one division of level in seconds of arc.

v^1 = value of one division of level in millimetres per metre. Then

$$v = \frac{2\,(r^1 - r)}{k \sin 1''\,(d + d^1)} \text{ and}$$

$$v^1 = \frac{2000\,(r^1 - r)}{k\,(d + d^1)}$$

Tables.—With the value of one division of the level, tables will be constructed showing the correction to be applied to a rod reading for an observed inclination of the level and for a distance determined by interval between extreme threads.

If the level bubble is well ground, equal displacements of the bubble, say of two divisions, will correspond to equal displacements on the rod.

Level Fastenings.—Before using the level, or determining its value, the fastening of the tube in its case should be examined. One end should be clamped down just tight enough to prevent the tube from moving easily but not tight enough to strain the glass. The other end should be lightly clamped so that the tube may be free to expand and contract with temperature changes. The cotton packing at the ends should not exert a lateral strain on the tube. All level tubes will be numbered and have their numbers marked upon them.

Inequality of Telescope Rings.—In order to determine the inequality in the telescope rings, the instrument should be mounted on a stone pier or other firm support and carefully levelled. The ends of the horizontal bar directly under the wyes should be firmly supported by blocks or large nails to prevent motion of the instrument in a vertical plane. The level should be carefully adjusted and the instrument clamped to prevent its moving in azimuth. Now with the eyepiece of the telescope over the elevating screw, note the reading of the bubble when level is set on telescope, both in direct and reversed position. Now reverse the telescope in the wyes, and read the level as before. Several sets of observations should be made.

Let b, b^1 = inclination of telescope as denoted by means of level readings with telescope direct and reversed, then the inequality of rings $p = \left\{\frac{b-b^1}{4}\right\} v' =$ value of the inequality of rings in millimetres per metre.

Sixteen determinations of the value of p of two instruments in use on the Lake Survey gave probable errors of $\pm$ 0″·046 and $\pm$ 0″·041.

The inequality may be expressed in seconds of arc if desired, but for purposes of computation is best expressed in millimetres per metre, as it can then be combined directly with the errors of adjustment of level and collimation.

Centring of Object-glass.—The centring of the object-glass will be examined. This may be done as follows:—

Draw out the eyepiece until the threads are no longer visible. Direct the telescope upon some well defined object, and while looking at it, rotate the telescope in its wyes. If the object remains steady, the object-glass is sufficiently well centred. Should the object appear unsteady, the fault can only be remedied by a maker. The objective should be firmly screwed into the telescope.

Wire intervals.—The values of the wire intervals will be determined as follows:—Set up a rod at carefully measured distances of 10^m, 20^m, 30^m—100^m from the instrument. Read the rod ten times at each distance. The rod may be altered in elevation, the level may be caused to change, and the telescope may be rotated 180° (inverted) in order to change the position of the wires, or threads, on the rod.

Taking the mean of the ten observed differences of readings of the extreme threads at each station occupied by the rod, a table will be constructed giving in metres the distance of the rod from the instrument for any observed difference of reading between extreme wires.

Length of Rods.—Unless the rods used have been previously compared with some known standard, they will be compared with each other and their relative lengths determined. This may be done by establishing two fixed points, or two foot plates, at equal distances from the instrument and differing in elevation about $2^{m}\cdot7$. The distance should be about 10^{m}. Determine the difference of elevation of the points by reading each rod on each point. A comparison of the resulting differences of elevation will give relative lengths of metres on rods. Ten measurements with each rod will be determined. The elevation of the instrument will be slightly changed between each set in order to eliminate errors in estimating the millimetres. Each rod will be numbered and have its number marked on it. The rods should also be kept dry and provided with canvas covers to protect them while being carried to and from work.

The distance, which will be called A, between the zero of graduation of the rod and the bottom of the steel spur on which the rod stands will be carefully determined ; this distance should be made exactly the same for each pair of rods by filing off the steel spur if necessary. This may be determined by measuring the distance between bottom of spur and zero or first graduation on rod by the use of a right angled triangle and scale. It may also be determined by means of another levelling rod, the graduations of which commence at the foot of the rod, by determining the height of the instrument above some fixed point and subtracting it from the reading of the rod to be determined. The relative lengths of the rods must be known.

Whenever a benchmark is connected with in such a way that the rod is not placed directly on the B. M., this quantity A enters into the computation of difference of elevation.

Adjustments.—Before commencing work at any time, all adjustments will be carefully made.

The Telescope will be collimated by having a rod set up at a distance of 50^{m} and noting the position of the wires on the rod when the telescope is normal and the bubble centred, and when inverted or rotated 180° about its axis and the bubble centred, then repeat with instrument in first position.

Let r = mean rod reading when the telescope is normal.

Let r^{1} = mean rod reading when the telescope is inverted.

Let D = distance in metres from instrument to rod. Then collimation error $C=\frac{r^{1}-r}{2D}$, in millimetres per metre.

The collimation error of the mean of the horizontal threads should not exceed $0^{mm}\cdot025$ per metre.

The horizontality of the horizontal wires will be examined by moving the telescope in azimuth so that the rod shall appear to move through the field of the telescope. If the threads are horizontal the reading on the rod will be the same, the position of the level which should be closely watched, remaining the same.

If the threads are found to be not horizontal they will be made so by turning the telescope a small amount in the wyes. When the thread wires have once been made horizontal, small screws which abut against projection of wye above elevating screw should be so adjusted that when they press against this projection the wires are horizontal. If the vertical thread is then inclined, as shown by the plumb line attached to the rod, it must remain so.

To adjust the striding level, i.e., to make the tangent of the level tube parallel to the upper surface of the telescope rings, it is necessary to make a lateral adjustment and a vertical adjustment as follows :—

To make the lateral adjustment, raise the clips fastening the level to the telescope, and revolve the level about the telescope a short distance each side of the vertical. If the bubble runs in opposite directions when on opposite sides of the vertical, the level is to be adjusted by means of the opposing horizontal screws at one end of the level until such is not the case.

To make the vertical adjustment, set up a rod at a distance of about 50 metres and read the wires with the telescope normal, level direct and the bubble in the centre ; reverse the level, centre the bubble and read the rod ; then read the rod, with the level in the first position, to ascertain if any changes have occurred during the observations. Be careful to eliminate parallax when reading the bubble in the mirror.

Let r = mean of rod readings with level direct.
Let r^1 = mean of rod readings with level reversed.
Let D = distance in metres from instrument to rod.

Then error of inclination, $I = \frac{r^1 - r}{2\,D}$ in millimetres per metre.

This error is to be adjusted by the opposing vertical screws at one end of the level case. The error of adjustment must not be allowed to exceed two divisions of the level. Care must be taken that the telescope rings are free from dust while adjusting the level. After having made the vertical adjustment it will be necessary to examine the lateral adjustment again, since making one of these adjustments affects the other.

To make the tangent of the level tube and vertical axis of revolution perpendicular to each other, loosen the small clamp screw at one end of the horizontal bar fastened to the vertical axis and by means of the elevating screw raise or lower that end of the upper horizontal bar until the telescope can be rotated 180° from any position and have the level reading the same in both positions.

To adjust the level attached to the rod, set up the rod in its tripod in such a position that when a plumb line is attached to the small hook near the top of the rod, the point of the plumb bob shall coincide with the point of a small cone attached to the rod near its foot. Now bring the level bubble to the centre by means of the levelling screws. In making this adjustment the rod should not be

exposed to the wind as the plumb line is influenced thereby. This adjustment will be made at least once each day.

Setting up the Instrument.—Each time that the instrument is set up at a station, its axis will first be made vertical by means of the levelling screws in such manner that the telescope may be turned around the horizon without the bubble of the level running a great number of divisions. The telescope is finally made horizontal by means of the elevating screw. The bubble must be in the centre at the moment of observing.

Sheltering the Instrument.—The instrument when in use ought always to be sheltered from the sun and wind. It is carried from station to station without being dismounted, but the level should be taken off and carried in the hand. The small clamp screw at the end of horizontal bar, and the large screw which fastens the instrument immovably to the tripod, should both be turned tight before moving the instrument.

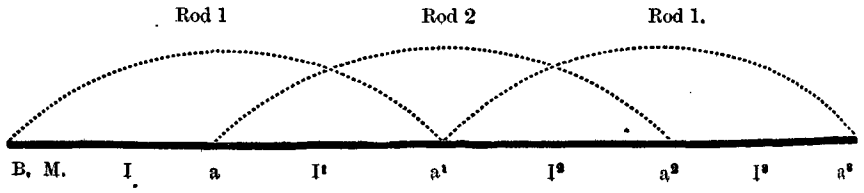
Holding Rods.—The rods must be placed on the plates or pins which accompany them and held in a vertical position as indicated by the spherical level attached. It is advisable to always use the same rod with the same foot plate. In placing the foot plates, great care should be taken that they be horizontal, on firm ground, and not liable to change. The surface of the ground, if not firm or level, should be removed. When pins are used in hard ground they should not be driven down hard but only far enough to be stable ; they will rise during observations if they are driven hard.

Errors of Adjustment.—The errors of adjustment of collimation and inclination will be determined at beginning and end of each series of observations, that is to say, after having mounted the instrument and before dismounting it, and in all cases at least once each day. If the instrument has been deranged by a jar, the corrections must be determined anew.

The algebraic sum of the errors of adjustment must not exceed two level divisions, and commonly should not exceed one. All the details of the determination of the errors of adjustment must be entered in the note-book in their proper place. It is always advisable to have the errors of adjustment as small as possible, and necessary that they be well determined. The time of making these determinations will be recorded in the note-book.

Duplicating Work.—In all work along the main line of levels each observer will duplicate his own work by running over the line in opposite directions, preferably under similar conditions as to illuminations, etc.

Order of using Rods.—While connecting two benchmarks the order of using the rods will be as follows :



In the above figure let I, I^1, I^2 ——, etc., represent the successive stations occupied by the instrument. B. M., a^1, a^3——, etc., the positions occupied by Rod 1, and a, a^2——, etc., the positions occupied by Rod 2. The instrument being set up at I. Rod 1 is placed on B. M. and Rod 2 at a, making the distance I—a equal to I—B. M. Rod 1 is then read and immediately afterward Rod 2. The time elapsing between these readings should not exceed five minutes and commonly will not exceed one minute. The instrument is then carried to I^1, and Rod 1 to a^1, the distances a—I^1, and I^1—a^1, being equal. Rod 1 will then be read and immediately afterwards Rod 2.

The instrument will then be taken to I^2 and the rods read in the order 1, 2. Work will be continued in this manner until the other benchmark is reached. Rod 1 must be placed upon this benchmark, which will be the regular order if there have been an even number of instrument stations. If there have been an odd number of instrument stations, at the last station use Rod 1 for both backsight and foresight.

If the lengths of metres on rods are the same and the values of A of the rods are equal, the stretch may be closed on either rod. While levelling, the rate of progress in favourable weather will be about one kilometre per hour.

In order to reduce the discrepancies due to settling of the instrument, the order of reading the rods will alternate. That is, at I the backsight will be read first and then the foresight; at I^1 the foresight will be read first and then the backsight, and so on throughout the length of the line.

Order of Observing.—After having properly levelled the instrument at any station, always making the vertical wire occupy the same relative position with regard to the centre line of the rod, the observations will be made and recorded in the following order: The bubble of the level being kept in the centre while threads are being read; first read the level; then the position of the threads on the rod will be read, the millimetres being estimated; and finally the level will be read again. The observer will then read the rod a second time to make sure that no error has been made. The recorder will then take the differences between the readings of the middle and extreme wires to guard against errors, and if these differences denote any error the observations must be repeated. If an error exists it will be shown by too great a difference between the differences. This is a most important check and must not be neglected. These differences will also serve as a check upon the distances between the instrument and rods.

The recorder should also check the level readings, when bubble is not centred, to make sure that errors of whole divisions have not been made. This may be done by summing up the readings and noticing the length of the bubble.

Reading Level.—In reading the level by means of the mirror care should be taken that the position of the eye is such that there will be no parallax. Such positions can be determined once for all when the mirror is at its greatest angle of elevation, by a second person reading the level directly while the observer finds the position from which the reading of the level in the mirror is the same.

Form of Field Notes.—The notes will be kept in the form given in note-books, as shown in the sample below. When once a number has been written down it must not be erased or made illegible. If wrong, a line will be drawn through it and the correct number written above.

(Left hand page.)

Date, October 22, 1898.

BACKSIGHT.

Thread Readings.	Means.	Diff. of Threads.	Level		Rod.	Remarks.
			Eye.	Object		
1196 ...	... ...	128 ..	.....	.....	.....	
1324 .	1320 3	117 ..	15 5	15·5	18	T. B. M. 249.
1441 ...	... ...	245 ...	.....	... .	.....	

(Right hand page.)

Observer, W. S. WILLIAMS.

Level No. 4.

Recorder, E. E. WHITEHEAD.

Tube No. 214 Fauth.

FORESIGHT.

Thread Readings.	Means.	Diff. of Threads.	Level.		Rod.	Remarks.
			Eye.	Object.		
1068 ...	... ...	127 ...	.....	.....	.....	
1195 ...	1192 0	118 ...	15·5	15·5	19	
1313 ...	.. ..	245 ...	.....	.....	... .	

Length of Sights.—The lengths of sights taken will depend upon the condition of the atmosphere, but the rod should always be near enough to be seen distinctly. It will be seldom that lengths of sights greater than 100 metres can be taken. The backsight and foresight corresponding to any instrument station must not differ in length by more than four metres, and the sum of the lengths of the backsights and foresights between any two benchmarks should be equal.

If the observer has the slightest cause to think the instrument has been in the least disturbed, or that the refraction has changed between the times of reading the two rods, he should repeat the observation until satisfactory results are obtained.

Crossing Streams.—Whenever it is necessary that the line of levels should cross a river or other wide obstruction, a narrow place should be chosen. Firm points should be set upon the two banks, levels in good adjustment are set up on opposite sides of the stream about 10 metres from each benchmark, and both levels go through the same operation. The distant rod will require a target. Each observer first reads on the B. M. nearest him, once with the telescope

normal and level direct and once with the telescope inverted and level reversed then takes simultaneous readings on the rod across the river with the instrumen in the following positions :—

1. Telescope normal, level direct.
2. Telescope normal, level reversed.
3. Telescope inverted, level direct.
4. Telescope inverted, level reversed.
5. Telescope inverted, level reversed.
6. Telescope inverted, level direct.
7. Telescope normal, level direct.
8. Telescope normal, level reversed.

These 8 readings constitute one set for the direct run. Then take 8 more readings in the same order for the reverse run, then each observer turns to the nearest B. M. and reads as he did at the beginning. Observers and instruments change places and repeat the observations at these new stations. The simultaneous levels eliminate refraction, the change of station eliminates curvature and small instrumental errors for each individual instrument. Unless good results are obtained the observations should be repeated until the results obtained come within the prescribed limits of error. If but one level can be used the operation will be performed in the same order, but the time occupied in crossing must be as small as possible.

Permanent Benchmarks.—Permanent benchmarks will be established at intervals of three miles along the river and five miles on lines connecting the river line proper with the other levels or benchmarks.

These benchmarks will consist of a thoroughly vitrified tile 4″ × 18″ × 18″ placed three feet below the surface of the ground and surmounted by a 4″ wrought-iron pipe as a surface mark. The tile should have time to settle before levelling to it. Both tile and pipe will be suitably marked to designate the character of the point. In the centre of the upper surface of the tile a copper bolt will be leaded, the upper surface of which will be the point of reference. These benchmarks will be placed where they can be easily found and where they will not be disturbed. Property corners should be utilized where practicable.

In addition to the above, benches should be established on permanent brick or stone structures by leading into them a horizontal or vertical copper bolt with the letters U. S. P. B. M. cut near it. A small hole in the centre of the bolt will be the point of reference.

Connecting with Benchmark.—In connecting with a benchmark, if the bolt is vertical the foot of the rod is placed directly upon it. If the bolt is horizontal in the wall of a building or other structure, it will be connected with in the following manner : Set up the instrument in such a position and at such an elevation that the small hole in the bolt may be bisected by the middle thread without displacing the level by more than five divisions, using the elevating screw for making this bisection. Since the instrument can be raised or lowered about

two centimetres by means of the levelling screws, the instrument can be placed in such a position by two or three trials.

Now bisect the benchmark with the telescope normal and also inverted, noting the reading of the level. Read the rod on the plate with the telescope in both positions and the bubble in the centre. It is necessary to eliminate collimation of the middle wire by inverting the telescope since the collimation of the middle wire is not the same as that of the three wires. The quantity A (distance between the zero of the rod and the bottom of the spur) must be taken into account when a benchmark is connected with in this manner. The distance of benchmark from instrument must be determined and recorded.

Closing Work for the Day.—Whenever work is stopped at least two temporary benchmarks should be established. These will consist of large nails or spikes driven their entire length vertically into the base of trees, or in the tops of sound stakes. The mean elevation of these two benches will be used in continuing the work.

Describing Benchmarks.—Every benchmark will be fully described in the note-book and a careful sketch will be made of its surroundings. Its position with reference to the most prominent objects near it should be given by distance and direction. Public buildings, such as depôts, court houses, churches, etc., are the best positions for permanent benchmarks. In a village or town several permanent benchmarks should be established to insure at least one being always available.

Determine Elevation of Base of Rail.—If a railroad is crossed the elevation of the base of the rail will be determined, and if levelling along a railroad, the elevation of the base of the rail at depôts will be determined.

Gauge Zeros.—The elevation of the zeros of all water gauges and also the gauge benchmarks will be determined.

Datum planes of Cities.—The main line of levels will be connected with the datum planes of cities along the line and the elevations of these planes will be deduced.

U. S. Engineer Benchmarks.—The main line of levels will be connected with all accessible important U. S. Engineer benchmarks.

In reducing the observations the nearest tenth of a millimetre will be retained. The distance will be taken out from the table to the nearest metre.

The limit of discrepancy in closing a polygon will be—

$$3^{mm}\sqrt{\text{Distance in kilometres.}}$$

The distance referred to is the entire length of the polygon from B. M. 1 to B. M. 2 and back to B. M. 1, and the limit of discrepancy refers to the polygons between successive benchmarks. If the discrepancy exceeds the prescribed limit then the entire line must be re-run one or more times, or until the difference of the direct and reverse results is within the limit. In re-running lines, the third line run should alternate between direct and reverse directions so as to keep the total number of direct and reverse lines equal.

Field reductions of all precise level notes will be made and checked at the end of each day's work, so as to ascertain, before leaving the ground, whether the results come within the prescribed limits.

INSTRUCTIONS FOR TOPOGRAPHICAL AND HYDROGRAPHICAL FIELD WORK.

General Instructions.—A record will be kept showing the daily progress of the party. It will contain at the beginning, the organization of the party, and the names and rates of pay of all persons connected with it. It will also give a detailed account of all occurrences of any importance which may in any way be of use in reducing the work or in settling accounts.

At the beginning of each day's work, each note-book in use will give locality of work, date, name of observer and recorder, number of instrument used and corrections, if any, to readings of distance and azimuth. The date should be repeated at head of each page.

In recording notes, hard pencils will be used, and when an entry has once been made it should never be erased. Where an error has been made the record will be corrected by drawing a line through the first value and writing the new value above it. Corrections that are made after the work is done should be marked with the date of the change and the name of the person making the change.

All notes should be so full and plain that they could be readily reduced by one who had not seen the ground. This will require careful attention to details which may seem of trifling importance in the field.

All available information concerning the river and its adjacent banks, which will aid in the proper representation of the characteristic features on the map or be valuable in the study of their changes, will be fully noted.

Local names of bars, bends, streams or other features will be carefully noted and the proper spelling of all names to appear on the map will be ascertained.

Permanent marks, as reference points for future surveys, will be established at intervals of about three miles along the river. There will be two on each side of the river, nearly in a line, normal to the stream. The two nearest the river will be placed where they will be safe from the erosion of the banks for twenty years or more, and the others will be a half mile further back. Where the bluffs are near the river the outer marks may be omitted. These marks should, when practicable, be placed near roads, property lines, or other places where they can be easily found at any time. The marks are similar to those used for precise level benchmarks described on page 15. The tops of these marks should project not less than a foot above the ground. The above marks, in the later work, are established by the secondary triangulation.

Note-books will be fully indexed at the end of each day's work. Each note-book will be marked on the outside with a title giving locality of work,

date, names of chief of party and observer. All note-books will be entered on the office files and properly numbered as soon as parties return from the field.

The chief of party being responsible for the accuracy of the work done, should see that the work of each member of the party is properly checked and fully covers the ground required.

Tertiary Triangulation.—Where the secondary stations are more than three miles apart, a tertiary system will be carried giving points on either bank at intervals of a mile or less. This system will begin on a triangle side of the secondary system or a carefully measured base, and all of the available secondary stations will be used in the tertiary chain. The tertiary work will also close on a line of known length as a check on its accuracy. The discrepancy should not exceed 1 in 3,000. The system should be laid out and the angles read in advance of the topographers so that the azimuths and lengths of sides can be used in checking stadia work.

The station point may be marked by a pole two inches in diameter, stuck into the ground, and bearing a red and white flag, to distinguish it from the ordinary sounding flags. A strip of white cloth wrapped near the bottom of the pole will admit of the pointings being made so low down that errors arising from disturbance of the pole by the wind will be inappreciable.

For observing, the instrument may be placed on an ordinary tripod centred over the hole after the pole has been removed.

The angles should be read with a ten-second instrument in good adjustment, and should be repeated at least three times on different parts of the limb to check errors of reading.

It is desirable to have the first series read on azimuth. Having pointed to the first station, read to all of the others in succession. Pointings should also be made to all of the sounding flags in the vicinity as well as prominent objects on land, such as chimneys, houses, &c., the location of which will serve to check the topographical work.

For the second series, slip the lower limb 60°, and read to the stations in the opposite order from the first series. Shift the limb the same amount again and read the third series.

The river ends of the stone lines will be made points in the tertiary system, and whenever practicable, the stones should also be located trigonometrically.

Tertiary points which are likely to remain undisturbed for some time should be plainly marked with a strong stake two feet high, the number of the point, the initials of the observer and date being marked on it with red chalk.

Topography.—The detailed topography will cover a belt on each side of the river, which, in a wooded country or on the bluffs, will be about $\frac{1}{2}$ to $\frac{3}{4}$ miles wide, and in open country may reach about $1\frac{1}{2}$ miles. In this area there will be located, with transit and stadia, all points needed to plat accurately the important features, on a scale 1 : 10,000. In all work, the scale of the plat should be borne in mind, so that only such points be instrumentally located as can be readily plotted.

Beyond the above limits outline surveys will be made, defining streams, lakes, and the foot and main crests of bluffs with approximate elevations of same, within a limit of ten miles of the river. This work will be run with the transit and stadia, and will frequently be connected with the detailed topography.

Where the detailed topography does not cover the entire valley from bluff to bluff, profile lines will be run at intervals of about fifteen miles measured along the river. These lines will be preferably located at such places as will best develop the interior topography and will extend from the river to the bluff. The lines should be about normal to the river and should give a complete profile of the ground from the river to the bluffs together with the elevation of high water marks and the topographical features along the line.

The dates when the high waters occurred should also be obtained when practicable.

Both extremities of the line should be carefully connected with the located points of the general survey.

These lines may be run with a good transit having a telescope level and good needle. The level should be used direct and the three horizontal wires should be read so as to eliminate errors of reading the rod.

Where the bluff line is beyond the limits of the detail topography the high water line or limits of overflow will be located along near the base of the bluffs. In most cases this can only be determined by frequent inquiry among the residents and care should be taken to verify the information thus obtained as far as practicable.

The dates of the floods should also be ascertained.

Full notes will be kept of all such information in order to facilitate the plat-ting and reduction of the data collected.

In locating the outlines of the bluffs, levels will be carried with the transit, and vertical angles will be read to points locating topographical detail in the same manner as in the regular topography.

Within the limits of the detailed area there will be located the top and bottom of the river bank proper, the shore line of islands and bars, the banks and water lines of all waterways and lakes with elevations of their water surfaces and depths, the points where the slope of the ground changes either in direction or inclination, the limits of rock ledges, the approximate limits and kinds of cultivation, and forests, roads, levees, fences, houses, &c., and in fact everything that may be necessary to a truthful representation of the section surveyed.

A sufficient number of elevations will be determined on the bottom lands to admit of putting in contours five feet apart. In a wooded area this will require cross-sections at intervals of 500 metres or less. These should preferably be the continuation of lines sounded across the river. The space between the lines should also be examined, and if any important features are found, they should be located. When the trees are too close together to admit of long sights, it will be more expeditious and sufficiently accurate to use the compass needle for obtaining the direction, as it will then only be necessary to set up at alternate stakes.

The bluffs within the detailed area will be shown by contour lines 20 ft. apart, the bluff curves being all some multiple of 10. The bluffs in the outline area may be shown by hachures.

Boundary lines, such as state, county, township, &c., coming within the limits of the survey, will be carefully located.

Section or township corners, where they are well identified, will also be connected with.

Great care must be taken in running out the stone lines. The azimuth of the lines must be accurately determined, and all distances will be carefully read, both forward and back. Each stone will be occupied instrumentally, and when practicable, the azimuth from onestone to the next will be read, and readings will be made to surrounding objects, both as checks on the located positions of the stones and to aid in finding them in future time. A careful sketch and minute description will be given of each benchmark thus located.

All sounding flags, water gauges and benchmarks will be located.

In running the main transit line along the shore sufficient check shots will be made to known points on the opposite shore to prove the accuracy of the positions given for the transit stakes. Such check shots should in fact be made use of in all parts of the work, so that errors of azimuth and distance may be detected and located. They also furnish means of correcting errors of position if any occur.

The error of level carried with the transit should never exceed one foot for the longest distances. In good work the discrepancies will rarely reach 0·5 ft. The work will be frequently checked by starting and closing on points whose elevations are known.

Distances and vertical angles between transit stakes will be read from each end of the line. On transit lines, the distances between stakes read with stadia, should never exceed 500 metres at a single reading unless they can be checked by intersections or other means. Single shots to distant objects may be read as far as the figures of the rod are distinguishable.

The transit stakes of each observer will be numbered consecutively in the reach covered by the season's work and each stake will be marked with its proper number and the initial of the observer so that it can be readily identified when connected with by others.

Field sketches will be made by the topographers, on sheets of suitable size to fold and place in note book. All points located instrumentally will be platted and the points numbered in the note-books and on sketches. The sketch will be completed on the ground, except the contours, and the direction of these will be indicated by showing the axes of sloughs, depressions and ridges.

The character of the immediate river bank will be frequently noted so as to show whether it is rock in place, loose rock, sand or silt, steep or sloping, caving or stable.

Checks on azimuth and elevation should be frequent and when obtained should be marked in the note-book in such a way that the amount of error will be

plainly shown and where the correction should be applied. Notes that are not full in this particular will always be open to suspicion which will throw doubt on the observer's honesty and the reliability of his work.

Discrepancies in closing on triangulation points should never exceed 0° 05′ in azimuth or 1 in 500 in distance. As a rule the discrepancies should be far within these limits.

The notes will be kept in the following form :—

(Left hand page.)

Observer, F. G. RAY.

Recorder, C. MCDONALD.

Objects.	No. of Pointing.	Ver. A.	Ver. B.	Distance.	
				Read.	Corrected.
		At □ 23, H. I. 176.			
□ 22	.....	274° 07′ 30″	94° 08′	234	....
Bank of slough	1	66 00	.....	322	....
Corner of fence	2	137 40	.....	128	....

(Right hand page.

Instrument, Ward. No. 154.
Locality, La Crosse, Wis.
Date, May 25, 1897.

Vertical Angle.	Dif. of Elev.	Elevation.	REMARKS.
		692·3	Sketch No. 6.
+0° 02′	+ 0·45	692·75	
−0 40	−12·3	680·0	
−2 15	−16·5	675·8	

NOTE.—Distances are expressed in metres, elevations in feet.

Ordinary Levels.—There will be a line of levels run along each bank of the river, the ordinary wye level being used for that purpose.

All turning points will be numbered so that the topographers can readily identify the points connected with.

The ordinary level lines will connect with all precise benchmarks in their vicinity, and also determine elevation of base of rail at stations and bridges crossing the river.

The errors of closure should not in any case exceed 0·2 ft. for the longest intervals. The two lines will check on each other at intervals of not more than 3 miles or in the vicinity of each stone line.

The elevations of stone line benchmarks will be determined by duplicate lines of levels, the discrepancies between which should not exceed 0·05 ft. The adopted elevation will be the mean of the two determinations.

The elevations of all permanent stations near the river except those on the bluffs will be determined. Benchmarks will also be established on each bank at intervals of about a mile. These may be placed on buildings, trees or other permanent objects near the river. A careful description, sketch of location and corrected elevations of all benchmarks will be made and entered in the note-book. These notes should be so full as to enable one not familiar with the ground to find the marks even after a lapse of several years time.

During the stay of the party at a place a temporary water gauge will be maintained. This may be of the usual form of stake gauge graduated to feet and tenths. Readings will be taken on this gauge, estimating to hundreths, three times a day and recorded in a gauge book. The usual hours for reading are 6 A.M., 12 N. and 6 P.M.

All these temporary water gauges will be connected with by duplicate lines of levels from the nearest benchmarks and the elevations of their zero points entered in the gauge book. The elevation of the zero should be tested whenever there is a probability that the gauge has been disturbed.

The elevations of the water surface will be determined at the extremities of sounding lines at intervals of not more than 400 metres, and the time of the observation will also be entered in the note-book. This when corrected for change of stage as shown by the temporary gauge readings will give the slope and also serve to check large errors in levelling.

Elevations of transit stakes and high water marks will be determined whenever it is practicable.

Level notes will be kept in the following form on the left-hand page of the note-book, the other page being reserved for sketches and remarks.

RIGHT BANK, NININGER, MINN.

September 13, 1897.

Instrument—B. and B. No. 616. W. H. ROPER, Observer.

Objects.	Back Sight.	Height of Instrument.	Fore Sight.	Elevation.
Cap of B. M. $\frac{254}{3}$	1·200	699·972		698·772
T. P. 773	3·460	697·362	6·070	693·902
Water surface at ⊙ 97, 2-30 P.M.			13·740	683·62
T. P. 774	3·174	695·743	4·793	692·569
□ 913 Williams			12·000	683·74
T. P. 775			4·685	691·058

River crossings for connecting the two lines of levels will be made by the two observers taking ten simultaneous readings across the river in opposite directions. Then the observers and instruments should change places and repeat the observations. (See instructions for precise levels, page 259.)

The instruments should be in good adjustment, and when once focussed for the long distance should not be changed until the observations are completed. The mean of the values thus determined will be taken as the true value.

Hydrography.—A continuous record of the stage of the river will be derived from a suitable gauge read three times a day, its zero being referred to a known benchmark as soon after it is set as practicable.

Sounding lines will be run normal to the stream at intervals of 250 metres, and the soundings on these lines will be as close together as practicable. These lines will be numbered consecutively.

A continuous longitudinal line passing through the deepest water on each section will be sounded.

On all crossings there will be sufficient soundings to determine the least channel depth between the pools.

As many soundings as practicable will be located by means of angles read simultaneously between located points on shore, with two sextants in the sounding boat. Intermediate soundings can be interpolated by taking them at equal intervals of time.

Where the conditions of width and other elements are suitable, the soundings may be located by means of a transit at one or both ends of the line. The distances from the instrument to the sounding boat to be read at convenient intervals of time on a vertical stadia in the bow of the boat. The boat should be kept on the line by means of flags or ranges.

If the above appliances are not at hand the soundings may be located by intersections obtained with two transits located at suitable points.

The character of the bottom will be frequently determined by means of a tallowed lead.

In water less than ten feet deep it is convenient to use a pole divided to feet and tenths. A 10-pound lead is suitable in water from ten to forty feet deep. In greater depths it is desirable to use a lead weighing from fifteen to twenty pounds.

A firmly twisted or braided hemp lead line, $\frac{3}{8}$ of an inch in diameter, should be used. It should be marked with leather or cloth tags at intervals of one foot, the ten foot marks being made conspicuous. The length of the lead line from the end of the lead to each ten-foot mark must be tested at the beginning and end of each day's work and the result entered in the note-book. The lead line should be accurately marked so as to avoid corrections as far as practicable.

The beginning of each line sounded will be headed in the note-book with the number of the section. A description of the character of the banks at intervals of about half a mile will also be entered in the note-book.

The elevation of the water surface at the time of sounding may be determined for each line by means of the levels as already described under the head of ordinary levels.

The notes will be kept in the following form :—

(Left hand page.)

SOUNDINGS IN VICINITY OF BATON ROUGE, L.A.

Observers—T. C. HOCKRIDGE, L. C. DZIATZKO.

Recorder—A. L. MONTGOMERY.

Time.	Observed depths.	Angles and Ranges.	Character of Bottom.
		Section 25, from ⊙ 25 R. B. to ⊙ 25 L. B.	
		C. P. 10, C. P. 9, ⊙ 25 L. B.	
7-40-30	1	15 feet from ⊙ 25 R. B ...	Mud.
41	6		Mud.
30	37	42° 30′ 52° 33′	Mud.
42 ..	65		Mud.
30	64	50 22 55 31	Sand.

December 9, 1897. (Right hand page.)

Leadsmen—M. FAHEY, J. H. HILT.

Corrections. Lead line and Stage.	Corrected Depths.	REMARKS.
O. K.		Bluff clay.
O. K.		
—1·0.	36	
—2·0.	63	
—2·0.	62	

The angles read to locate soundings will be numbered consecutively for each day's work, and the soundings located will be marked with corresponding numbers.

Platting.—The co-ordinates of all tertiary stations, stone line benchmarks and secondary stations, will form the basis for platting the topographical detail. The work will be platted on a scale of 1: 10,000. The field plats will be on tracing linen 30 inches wide and in such lengths as will cover the topography to the best advantage. On these sheets the projection and geographical positions will be platted in the office. These field plats need not have the protractor circle printed on them, but can be used to better advantage over an accurate paper protractor of suitable size.

Care should be taken to roll the sheets in the same direction as original roll from which they were cut, in order to obviate the difficulties arising from change of scale.

These transparent field plats admit of transferring direct to detail chart and also facilitate the transfer of the details from sketch.

Parallels and meridians, one minute apart, will be projected on the field plats and shown by fine red lines properly numbered. From these the triangulation

stations will be platted. As this is the ground work for subsequent detail, it should be carefully done and checked over to insure its accuracy. All triangulation stations, stadia stakes and sounding flags, and their elevations, should be marked on the plats in red ink before the detailed work is put in.

All of the detail must be carefully platted and positions verified by check shots when such are available.

The contour lines and other outlines should preferably be put in by the observer who located them in the field.

Field plats will be laid out in such a way as to show both banks of the river with the adjacent topography on the same sheet whenever it is practicable. If the sheet is not large enough, plat the remaining work on a new sheet rather than enlarge by pasting pieces to the first sheet.

Banks that are too steep to admit of drawing in the contours, and abrupt banks of less than five feet in height will be shown by hachures.

The elevations of water surfaces for each day's work will be plainly written on the plats.

All field plats must be completed in the field at least far enough to detect any instrumental errors in the field work before the platted area is out of reach. Hard pencils will be used in platting.

Each field plat will bear a legend giving locality and date, the names of the chief of the party, the observers and draftsman, the numbers and pages of the note books from which the notes were derived, and any other information that may be useful in the final reduction of the work. These data should be noted as the work is platted.

When all of the points have been platted on the field plats, the details and contours will be drawn in with pencil. After this is done the entire plat should be inked including elevations, names of owners, character of vegetation, &c., and in fact everything needed to make the information obtained by the survey complete.

The contours and elevations may be drawn in brown ; all other details in black.

Care must be taken at the edges of the sheets to have the detail on successive plats join properly, and make sure that the ground is fully covered by the survey.

Nomenclature.—The word lake will be confined to the larger bodies of water, which are seldom if ever dry. They usually have a local name which should always be noted. Smaller and temporary bodies of water having no local names will be called ponds.

The word swamp will be applied only to ground which is covered with a growth of grass, cypress, elbow brush, willows, or such other vegetation as indicates that the area is generally wet, soft or spongy.

The terms bayou, or creek, will be applied only to main water-courses which connect lakes and swamps, or other drainage areas, with the river, and carry water to or from the latter, as the stage varies.

Minor swampy conduits will be called sloughs. This applies only to such as are not designated by local names.

The character of the material composing the bars and banks of the river will be frequently noted and carefully described.

The names of property owners or residents, of landings, wood yards, fields, patches of timber, islands, chutes, bends, bars, points, and other local names necessary to a full description of the section surveyed will be fully noted and entered on the field plats. The following signs and abbreviations will be used: Secondary stations, ⊛; tertiary stations, △; transit stakes, □; sounding flags, ⊙. Turning points in levelling notes will be written T. P.; benchmarks B. M.; temporary benchmarks T. B. M.; and precise benchmarks P. B. M.

On the field plats the precise benchmarks with their numbers and elevations will be written thus: P. B. M. 27 ⊙ 218′·032; stone line benchmarks thus: B. M. $\frac{1^0}{3}$ □ 219′·23, in which the numerator is the number of the stone line, and the denominator the number of the stone on the line, reckoned from the outer stone on the left bank.

The stone lines will be numbered consecutively upstream beginning with number one near Cairo, Ill. They are also numbered consecutively from Cairo southward to Memphis and from Memphis to Head of Passes.

All elevations in the topographical work will be referred to the Memphis datum plane.

To reduce elevations from the Cairo datum to the Memphis datum, subtract 13·13 ft. from Cairo datum elevations.

DATUM PLANES.

The Cairo datum plane is an assumed plane 290·84 ft. below the zero of the U. S. Engineer gauge at Cairo, Ill.

The Memphis datum plane is an assumed plane 190·84 ft. below the zero of the U. S. Engineer gauge at Memphis, Tenn.

The preliminary value of mean Gulf level at Biloxi, Miss., is 21·26 ft. above the Cairo datum plane and 8·13 ft. above the Memphis datum plane.

INSTRUCTIONS FOR GAUGE INSPECTORS AND OBSERVERS.

The regular gauges of the Commission shall be inspected and repaired at least twice each year at times preceding high and low water.

In view of the liability of mistakes arising from having gauge readings at the same place referred in different years to different zeros, no zero of a gauge shall be changed without action of the Commission.

The gauge inspector on visiting a gauge shall make careful level connection between the different parts of the gauge and the gauge benchmarks. He shall also carefully examine the records of the gauge keeper. The inspector is not required

to compute the corrections for each part of the gauge, as this can better be done after a study of the office hydrographs, but the inspector should endeavour to embody in his report full information as to periods of reading on any disturbed portions of the gauge and causes of such disturbance as far as may be obtained from the gauge keeper or other sources. The gauge should be repaired and left in good order as nearly as conditions of the river will permit. The bulletin board shall also be inspected and left in good order.

The regular printed form of inspection report will be filled out completely or reasons for not doing so noted thereon. This report will be immediately transmitted to the Secretary.

The gauge observers will be governed by the following instructions and the inspector when visiting the gauge is expected to ascertain if they are being followed strictly :—

1st.—Readings must be taken by the observer in person at the hours of 8 A.M. and 4 P.M. each day, or if unavoidably delayed always note the exact time when readings are taken.

2nd.—The stage as read must be recorded on the postal card addressed to the Secretary. This card must be carried to the gauge in the covers provided for that purpose, and the reading must be noted thereon in pencil as soon as obtained. The reading thus recorded shall not afterwards be inked in or altered. If the reading is discovered to be in error, the correct reading must be written above it, and an explanation made in column of remarks.

Copies of these readings will be entered in ink in the gauge book and duplicates of the cards will be made for the Engineer Offices, as shown by the addresses on said cards.

3rd.—The cards will be mailed as soon as practicable after the week's record is completed and the required copies have been made. The original card as recorded in pencil at the gauge will be mailed to the Secretary.

4th.—The bulletin should at all times show the stage to the nearest quarter of a foot. It will be changed morning and evening, whenever there is a change of stage amounting to a quarter of a foot.

5th.—The observer should carefullyguard against the destruction of the gauge, and whenever he finds it in danger he should establish a temporary gauge in a safe place, taking great care to have the readings agree with the original gauge, and to keep the temporary gauge in same position, in which it was used, until the visit of the inspector.

6th.—The column of remarks should be freely used to explain disturbances of the gauge, noting the time when readings change from one section to another, and in fact any information which may aid in making the records complete and perfect.

7th.—The gauge and bulletin will be put in good order by the inspector about twice in each year. In the interval the observer is expected to make such repairs as may be needed to keep the gauge and bulletin in good order.

8th.—At the end of each year the gauge book will be returned to the office of the Secretary and a new one will be supplied in its place.

9th.—Any serious accident to the gauge or bulletin, any sickness or absence of observer necessitating the use of a substitute, should be promptly reported to the Secretary.

INSTRUCTIONS FOR RIVER DISCHARGE MEASUREMENTS.

Discharge measurements will be made at extreme high and low stages of the river, in the discretion of the Secretary as follows :—

On the Mississippi river at Thebes (*46), Columbus (21), Helena (306), Arkansas City (438), Warrenton (605), Red River Landing (765), Carrollton (957).

(* Above Cairo.)

On the following tributaries : Tennessee, Cumberland, St. Francis, White, Arkansas, Yazoo, Red and Black. Also on the Atchafalaya River.

The stations on the tributaries shall be selected at points not affected by back water and, when practicable, near permanent gauges.

As far as practicable, discharge sections will be located near the lower end of straight reaches where for a mile or more above the section, the water at high stages flows in parallel threads, free from cross-currents, eddies and boils. The profile of cross-section should be fairly regular.

It is desirable to observe on the same cross-section from year to year, except in case of unfavourable local changes in the regimen of the river. In such case, after careful examination, a new location may be selected. A detailed report giving reasons for change, accompanied by a sketch showing new location, will be submitted to the Secretary for approval.

Except when otherwise especially instructed, not less than ten complete results of the river discharge, consisting of determinations of stage, cross-section and velocity will be obtained at each discharge station.

High water discharge will be measured as near the highest stage of the year as practicable, and should include the maximum stage.

Low water discharge will be obtained as near the lowest stage of the year as practicable.

The stage will be measured to the nearest hundredth of a foot, by carefully reading gauge rods located at each end of the section, at the beginning and end of each set of observations. When the section is near a permanent gauge the reading of this should also be recorded.

These gauges will be graduated to feet and tenths and accurately connected by duplicate line of levels with the permanent benchmarks of the general survey. On the tributaries, where this connection cannot always be made, permanent benchmarks should be left near the section for future reference.

The geodetic position of the section should also be approximately determined and platted on one of the published detail charts of the Mississippi River scale 1 : 20,000. For the tributaries, the best obtainable local maps will be used.

The cross-section will be determined by soundings taken with a lead of sufficient weight to secure correct vertical depths and at such intervals as will give an accurate determination of the irregularities of the river bed. This will generally require soundings at intervals of about 50 feet. The configuration of the banks near the shore, the distance between the shores, the locations of soundings and the water's edge should be determined with special care. If practicable, this should be done on each day that velocity is measured.

A three-eighth inch cotton sash-cord and a 20-pound lead will give good results in ordinary depths. Frequent tests of the length of lead line will be made and the discrepancies recorded in the note-books. In depths greater than 50 feet with velocity exceeding about 4 feet per second soundings will be taken by drifting over the cross-section.

Direction of flow.—At beginning of observations the direction of flow at the cross-section should be ascertained by means of double floats or by direction current meter. The sub-surface float will be run at mid-depth, except that occasionally a bottom float will be run where tidal effects might be expected.

When the current is found to deviate more than 8 degrees from a normal to the section proper, allowance will be made in the final reduction. When the deflection exceeds 15 degrees a better section should be obtained if possible. This is most important in high stages.

Determination of velocity.—The velocity will be determined with a suitable current meter, such as the Haskell meter or the later forms of the Price meter. A continuous automatic record of time and registrations is very desirable as it furnishes a means of ascertaining the pulsations in velocity and can be examined at any time to settle doubtful points developed in the computations.

The velocity stations on the cross-section should be near enough together to give a good measure of the velocity for the entire width. The shore stations should not be more than 50 feet from the water's edge and the distance between intervening stations should not exceed 200 feet except in case of very wide section during high water, this may be increased to 250 or 300 feet if otherwise observations could not be completed in one day. When considerable changes in the horizontal velocity curve occur the distance between stations should not exceed 100 feet. Special care should be taken to ascertain the change in velocity as the shores are approached. Over-bank discharge should be measured every two or three days when taking river discharge.

The axis of the meter should be in the direction of the flow of the water ; any variation from this, if ascertainable, should be recorded in the note-book Before beginning observations the meter should be adjusted to be horizontal when suspended freely in water.

The meter work at each station will consist of a run for mean velocity at six-tenths of the depth. The run should not be less than five minutes in length, with automatic registrations, and if any irregularities are noticed the length of time should be increased until satisfactory results are obtained.

Observations for velocity will be made with double floats every three or four days; these will also serve as an approximate check on the meter work. Calm days should be selected for running floats. In these observations the submerged float will be run at mid-depth. The sub-surface float should be a hollow cylinder about a foot high and ten inches in diameter; or it may be made of two vanes crossed at a right angle. The surface float should be about six inches in diameter on plan and be elliptical in vertical section. It should have sufficient buoyancy to support the sub-surface float and be of such form as will offer the least possible resistance to the current and the wind.

The two floats should be connected with a very fine cord of suitable length to leave the sub-surface float at mid-depth.

The floats will be run over a base about 400 feet long, the discharge section being at the lower end. The point where the float crosses the section should be accurately located.

The portion of river over which the float is run should have an approximately uniform cross-section and sections at middle and upper end of float path should be sounded at least once during the series of observations.

Meter Ratings.—Ratings should be made at the beginning and end of each season's work and at least once in twenty days during the continuance of discharge work; also whenever there is reason to suspect a change in rate. The field notes of these observations should be immediately transmitted to the Secretary's office, a copy being retained in the field. An approximate test, which will show any marked change in rate, can be made by noting the time required for the wheel to come to rest after revolving it briskly with the hand.

In rating observations the extremes should be well above and below the greatest and least velocities that will probably be observed in actual work.

Still water ratings should be made by drawing the meter well submerged, at a uniform speed through still water, along a base line of known length and noting the time and number of registrations. The water should be not less than 8 feet in depth and the submergence about 4 feet.

A good determination of the rate will require about 30 observations, well distributed for different velocities.

Running water ratings.—Will be taken in pairs, upstream and down-stream giving one result. Not less than 20 pairs of observations should be taken in a set.

The velocity of current should not exceed 2 feet per second to give reliable results.

Field records will be made in the regular note-books on the spot and must be sufficiently full and legible to accurately locate the cross-section, the soundings

and the velocity stations and will in general contain all the data required to compute the discharge without any further explanation.

Careful notes should be made daily of all phenomena pertaining to the flow of the water, whether it flows steadily in parallel threads throughout the section, whether there are boils, eddies or cross-currents, and all such information as may have a bearing on the question of the correct interpretation of the discharge measurements.

Field Reduction.—The chief of the party should make only sufficient reductions on the spot to enable him to detect irregularities in the river or errors in the work. These should be made after each day's work. These reductions will be made graphically as follows :—

The corrected soundings will be carefully plotted on cross-section paper to a scale of, say, $1''=200'$ horizontal and $1''=20'$ vertical. On this section should also be plotted, at each velocity station, the meter registrations to a common unit of time. This will indicate the distribution of velocities across the river.

When the velocity stations are at equal intervals across the river the mean velocity may be approximately computed by multiplying together the sounding and registrations at each station and dividing the sum of the products by the sum of these soundings ; the result will then be reduced to velocity in feet per second, using the nearest available meter rating. When the intervals are unequal the plotted section may be divided into intervals of 200 feet and velocities or registrations and soundings scaled off and used as above. In the case of float observations the latter method will always have to be resorted to.

Experimental Work.—When time will admit of it one or more sets of velocities in the vertical at each velocity station should be taken. These will consist of surface and bottom velocities and at each tenth of the depth for a run of about two minutes at each point. All the stations need not be observed on the same day. The surface velocity should be obtained as near the surface as the meter will work regularly and the bottom velocity at about one foot from the bottom. These notes need not be reduced in the field but should be immediately transmitted to the Secretary.

APPENDIX B.

LEVEE CONSTRUCTION.

SPECIFICATION.

1st and 2nd District.

THE work to be done under these specifications is the closing of existing breaks in levee lines, and the enlarging of levees in different levee districts as indicated below. The work will be paid for from money now available.

LOWER ST. FRANCIS LEVEE DISTRICT.

Closing Breaks, Enlargement and Repair of existing levees.

CREVASSES TO BE CLOSED, &c.	LOCATION. *NEW NOTATION.	APPROXIMATE YARDAGE. CUBIC YARDS.
Caruthersville	29 M.	62,000
Half Moon Bayou	39 M.	4,000
Lintdale	43 M.	29,000
Midway	45 M.	43,000
Crooked Bayou &c.	61 M.	2,600

* **NOTE**—NEW NOTATION.—Mile posts are now placed along the St. Francis levee line, and numbered consecutively beginning at the upper end of the line.

WHITE RIVER LEVEE DISTRICT.

CREVASSES TO BE CLOSED, &c.	LOCATION. MILES BELOW CAIRO.	APPROXIMATE YARDAGE. CUBIC YARDS.
Williamson's—1st Section	309 R.	220,000
2nd Section		220,000
Fitzhugh	311 R.	56,000
Westover	321 R.	20,000
Schoolhouse Bayou &c.	342 R.	60,000

UPPER YAZOO LEVEE DISTRICT.

Enlargement of existing levee, including exploration of old levee where necessary, from the beginning of the south half of Section 76 southward, as far

as the available funds will permit. Enlargement may be made on either or both sides as directed by the Engineer in charge. It may be necessary at places to haul earth over the levee. Bidders will state the additional price at which they will do such work.

NATURE OF WORK.	LOCATION.	APPROXIMATE YARDAGE. CUBIC YARDS.
Enlargement to 1 ft. above '97 H. W., and topping of 50 c. y. per station (100 ft.) and building banquette on land side	S. ½ Sec. 76	55,000
Same	Sec. 77	125,000
Same &c.	Sec. 78	125,000

The quantities given are approximate. The United States reserves the right to increase or diminish them to the extent that more detailed surveys, definite locations and closer estimates may make necessary or advantageous to the work.

Proposals will be received for the work in sections as indicated below. Bidders are invited to bid on any or all sections. If any bidder proposes to construct more than one section, he will state the total cubic yards he is prepared to accept. If he be the lowest bidder, such sections will be awarded him, within the amount stated, as may be most advantageous to the United States.

Character of Work.—Work under these specifications, either for enlargement or new work, will include all excavations and embankments required for the construction of the levee ; cutting all ditches or drains about or contiguous to it ; the excavations and embankments necessary for reconstructing public roads and passways, in cases where they are destroyed or interfered with by its construction, and all other excavations and embankments connected with or incident to its construction ; grubbing and clearing of all timber and vegetable matter ; sodding with Bermuda sod, and the felling of all trees within one hundred feet of the base of the levee on both sides.

Method of Construction of New Levees.—The ground to be occupied by the levee must be cleared of logs, trash, brick, weeds, grass, leaves, and all other perishable or objectionable material to a distance of five feet outside the slope stakes. Next shall follow in the order indicated by the Engineer in charge, or his designated agent, the thorough breaking of the surface to a depth of six inches between the slope stakes, and the grubbing up and removal of all trees, stumps, and the larger roots, and also all buried logs, stumps and other perishable matter, over the same area, including a zone five feet wide outside the slope stakes. All of the matter so grubbed and excavated shall be conveyed to a distance outside the slope stakes of not less than five feet. Such of this matter as shall remain undiscovered until the muck ditch is dug, shall then, in

like manner, be excavated and removed ; after the satisfactory completion of the clearing, grubbing and surface breaking, and the removal from the ground of all débris, a muck ditch will be cut of such dimensions and in such location as the Engineer in charge shall direct. After inspection and measurement, the muck ditch must be filled in, if possible by scrapers, with approved material procured from without the base of the levee, and thoroughly tamped while being filled, by the teams passing over the material, to the satisfaction of the Engineer in charge or his designated agent. If it be impracticable to refill the ditch by scrapers, it will be done by men in the direct employ of the contractor, and under his immediate supervision, and the material will be tamped by mauls or by horses or mules passing over it as it is deposited in the ditch, to the satisfaction of the Engineer in charge. In no case will the refilling be let to station men. The fill and side stakes shall then be set by the contractor. All of the foregoing work shall be completed for at least three hundred feet in advance of the embankment. When this has been done, embankment construction shall be commenced, the first earth obtained from the borrow pits shall be placed on the land side of the centre line of the levee, the embankment shall then be carried up to gross fill or height, as directed by the Engineer in charge. Only clean earth free from trash, roots or other objectionable material, shall be placed in the levee. When so required, stump holes must be tamped as the material is thrown in them, and for this an extra compensation, to be determined by the Engineer in charge, will be allowed. When the embankment has been brought up to the proper height, it shall be dressed, and planted with living tufts of Bermuda grass, not more than two feet apart, well pressed into the earth and lightly covered with soil, to the satisfaction of the Engineer in charge, or his designated agent. The contractor will cut down all trees, both great and small, to a distance of one hundred feet from the base of the levee on both sides. The trees will be felled in such manner as not to fall on the levee.

Method of Enlarging Old Levees.—In the raising and enlargement of old levees, the material, excepting for the banquette, where one is constructed, will be placed on the river side, unless otherwise directed by the Engineer in charge or his designated agent. The portion of the old levee and the natural surface of the ground to be occupied by the new work will be prepared as described in Section 4 for the base of a new levee. The surface will be cleared of all perishable and objectionable material ; trees and stumps shall be dug out, hidden stumps and logs, where known to exist, excavated, and all this material removed not less than five feet beyond the side stakes. The grubbing will include a zone five feet wide outside the slope stakes, and also the slope of the levee not occupied by the enlargement. The surface to be occupied by the enlargement must be well broken and the sod thus destroyed wasted as provided above for other perishable material. All existing levees or parts of old levees must be left, except by special permission of the Engineer in charge, given in writing. In repair and enlargement work, the material shall not be obtained from the old

borrow pits, but on the natural ground on the side of said pits furthest from the levee. The trees, large and small, will be cut down on both sides of the levee within a distance of one hundred feet from the base.

Obtaining Earth.—In procuring material for the levee, the place will be designated by the Engineer in charge, or his designated agent, (always on the river side, unless otherwise directed,) and in excavating and removing it, care must be taken to injure or disfigure the land as little as possible. In no case must it be obtained within forty feet of the base of the levee on the river side, and the slope of the pit next to the embankment must not be steeper than two base to one perpendicular. If, from unavoidable causes, it becomes necessary to procure material on the land side of the levee, it must not be taken within eighty feet of the base. But it is not to be taken from the land side at all, unless upon the written order of the Engineer, designating the place. Any encroachments upon the limits of either side will be repaired before the levee is estimated and paid for. Borrow pits must not exceed three feet in depth on the side nearest the levee. From this point outward from the levee the depths will increase in proportion to the distance from the levee, not exceeding six feet at a distance of 300 feet from the slope stakes. In cases of light levee or small enlargements, where the borrow pits are not wide, the depth of three feet will not be exceeded at any point, unless otherwise specially authorized by the Engineer in charge.

Notes.—Notes will be furnished the contractor, giving width of crown and inclination of slopes, gross and net fills, bases on river and land side, and total base, and he will be held responsible for the embankment being constructed in exact accordance with the dimensions furnished.

Shrinkage.—The allowance for settling or shrinkage of embankment will be one-tenth for scraper work, and one-fifth for barrow, or scraper and barrow work mixed, regardless of the material used; and no embankment that is not carried up one-tenth or one-fifth higher than the established grade will be paid for. The allowance for shrinkage or settling must be so disposed on tops and slopes as to give the required width of crown, and to fill out the slopes so as to make plane surfaces from edge of crown to base of levee after shrinkage has practically ceased. Nothing will be paid for this settling or shrinkage. The contents of the levee, computed to the established net grade only, will be paid for.

Road Crossings.—Road crossings shall be constructed at such points and of such dimensions as may be designated by the Engineer in charge, or his designated agent, and will be paid for at the same price per cubic yard as the levee itself.

Drains, Ditches, and Channels.—Drains, ditches and channels for streams, when necessary for the proper execution of the work, must be cut by the contractor as directed by the Engineer in charge, or his designated agent, and the material excavated, when placed in the levee embankment, will be paid for at the same price per cubic yard as the levee itself, but will not be paid for if the

material is not deposited in the levee. Exception is made in cases where the ditch or other drainage excavation is too remote to permit the material to be placed in the levee ; in such cases an extra compensation may be allowed, to be determined in each case by the Engineer in charge.

Excavation Work.—Where under these specifications, it is deemed necessary to cut through old levees or to cut out crayfish holes, the contractor will be paid for the measured excavation, after they have been refilled, at the same price per cubic yard as for the levee.

Road and Fences.—Wherever the route of the levee is traversed by public or private roads, commodious passing places must be kept in safe condition for use. In passing through farms, the contractor must erect and keep up such temporary fences as may be necessary for the preservation of the crops and protection of property. This work to be done at contractor's expense. In case of failure to do so, the Engineer in charge will order it done by hired labor, and will deduct the cost of the same from any sums that may become due the contractor under his contract. Public roads, crossing or running parallel and close to the levee, must be kept open during the progress of the work.

Damage or Injury to Work.—In anticipation of destructive floods during the progress of the work the Engineer in charge, or his designated agent, may require a protection of timber or other material to be constructed around the ends of the levee, and also a temporary protection levee to be built in front of the work, upon such locations as he may designate, and of such dimensions as he may direct, and may also require the base of the levee to be covered with a mattress, whenever necessary to protect the embankment ; for any of which work an extra compensation, to be determined in each case by the Engineer in charge, will be made. All damage or injury to work, resulting from flood or other cause, shall be sustained by the contractor till received by the Engineer in charge.

Force.—Within thirty days after written notice has been given the contractor to commence work he shall employ such force and outfit as shall be necessary to complete the work within the contract time ; if he shall fail to maintain this force and outfit or if it becomes evident to the Engineer in charge that the work is not being prosecuted with due diligence, and will not be completed in the contract time, the Engineer in charge shall have power to employ, at any rate of pay which in his judgment may be necessary, such additional labor, and to purchase such additional outfit as may seem essential to insure the completion of the work in the contract time, and place them upon the work, deducting the total cost of the same from any moneys due or to become due the contractor. The contractor shall personally superintend his work on the ground, or cause it to be done by a responsible and capable representative, and will also, on complaint of the Engineer in charge, or his designated agent, discharge any employee detected in violating these specifications.

Location of Work.—The Engineer in charge, or his authorized agent, shall have the power to designate the exact locality at which the work shall be

prosecuted ; also, the proportion of the force that shall be worked at such designated locality.

Extra Work.—No claim for extra work will be entertained, unless such extra work is done under written instructions from the Engineer in charge, or his designated agent, and these instructions must be presented with the claim. No charge shall be made by the contractor for hindrances or delays from any cause whatever in the progress of the work, but such hindrances or delays may entitle him to an extension of the time allowed for the completion of work, in the discretion of the Engineer in charge.

Changes in Dimensions.—The United States reserves the right to increase or diminish the height, crown or base of the levee while in process of construction, if it should be deemed advisable.

Frozen Material.—Frozen dirt, snow or ice will not be allowed in the levee. Such material must either be wasted or work postponed until thawing weather sets in. No extra compensation will be allowed for material thus wasted.

Settlement of Foundations.—Where a levee is constructed across a slough, or at any place where settlement of the soil on which the levee rests is anticipated, the contractor will erect, at his own expense, such structures for determining settlement as the Engineer in charge may designate, and shall construct the levee in such a manner as he may prescribe, and for all material used in restoring the sunken portions, the contractor shall be paid at the same price per cubic yard as for the original embankment, but he shall receive no compensation unless the instructions and directions of the Engineer in charge are fully complied with.

Superintendence and Employees.—The contractor shall personally superintend his work on the ground, or cause it to be done by a responsible and capable representative, who shall be satisfactory to the Engineer in charge. Any employee detected in violating these specifications will be discharged, on demand of the Engineer in charge, or his representative. Where work is let to station men, the contractor shall provide a competent foreman to superintend their work, who shall direct the manner of doing it and shall maintain a strict watch over them. No foreman shall have charge of more work than the Engineer in charge may deem advisable.

The use of barrels and boxes or similar contrivances for wheelbarrow runs is prohibited.

Price of Work.—All levees will be estimated in embankment and be paid for by the cubic yard. The muck ditch will be paid for once, after the levee over it has been completed, at the same price per cubic yard as the embankment. The excavations caused by the grubbing of stumps, removing of buried logs and cutting away crayfish holes, &c., will be paid for once after they have been refilled, at the same price per cubic yard as the embankment. It is to be understood that no compensation will be allowed for the refilling of muck ditch, stump holes or other excavations. It is further understood that the stated price per cubic yard

for levee work covers all work under these specifications, including the felling of trees, cutting drains, or any other work necessary to complete the levee in accordance therewith.

Acceptance of Work.—New levees will be accepted in lengths of 1,000 feet of continuous completed levee, and enlargement work in lengths of 2,500 feet of continuous completed work.

Payments.—Payments will be made on monthly estimates of fully completed levee, except sodding, reserving ten per cent. Payments, however, may be made for incomplete embankment when work is so constructed under special written instruction of the Engineer in charge.

Explanation.—The above specifications, if not understood, will be fully explained by the Engineer in charge, but if their requirements are wilfully neglected, no measurement or estimate will be made on the work until they are complied with.

Engineer in Charge.—It is to be understood that the Engineer in charge is the officer of the Engineer Corps of the United States Army who signs the contract on behalf of the United States, or his legal successor.

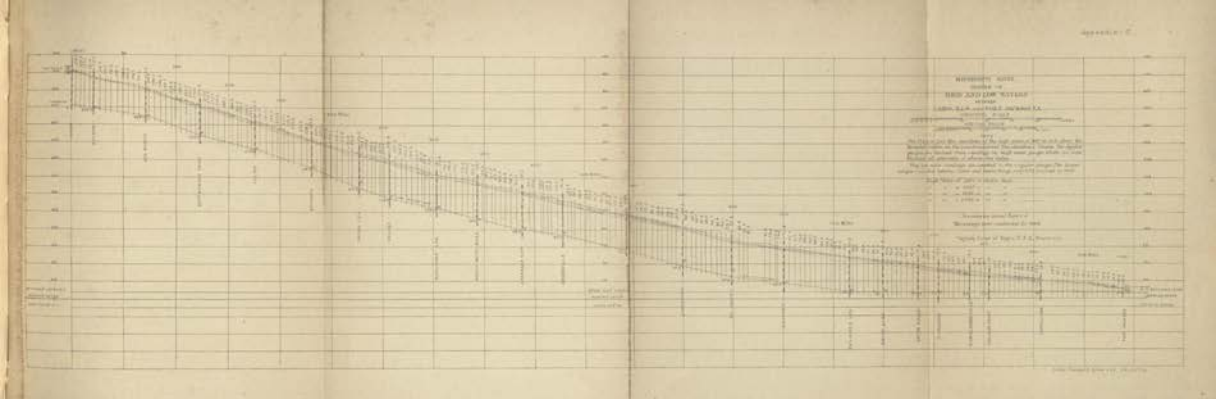
Disagreement.—In case of any doubt or disagreement arising under these specifications, the decision of the United States Engineer officer in charge shall be final, and he shall be the sole referee.

Date of Completion.—All new levees built to close breaks shall be fully completed in accordance with these specifications on or before January 15, 1898. All other work shall be completed on or before February 15, 1898.

When required by the Engineer in charge, the contractor must provide lodging and subsistence for the United States Assistant Engineer, inspectors and instrument men, rodmen and chainmen, at a reasonable price, approved by the United States Engineer in charge, and paid for by the United States.

Wheelbarrows.—Under no circumstances will wheelbarrows be used in constructing a levee, except upon special written permission of the Engineer in charge, when in his judgment it is not practicable to do the work with scrapers.

Prosecution of Work.—When the contractor enters upon the work he will be required to prosecute the same continuously, otherwise the engineering expenses incurred during any suspension of work will be charged against him.



Part of U. S. Dredge Fleet in Winter Quarters at West Memphis. Dec. 1898.

APPENDIX D.

IMPROVING MISSISSIPPI RIVER BETWEEN MOUTHS OF THE OHIO AND MISSOURI RIVERS.

SPECIFICATIONS FOR HYDRAULIC DREDGES.

THESE specifications are as of one dredge, but will apply to the two, which are to be alike in every respect. Proposals will be received for one or both.

SPECIFICATIONS.

The dredge is designed to have a hull one hundred and sixty feet in length, forty feet in width, and six feet six inches in depth, moulded dimensions. It is expected to have a draft, when completed ready for work, of about forty-two inches.

It will be operated by hauling in wire cables made fast to piles placed in suitable positions up stream and out from the sides of the dredge, and will make a channel twenty feet in width at the bottom, at each cut.

It is to be supplied with two centrifugal pumps with suction and discharge openings twenty inches in diameter, the discharge pipe to be immediately enlarged to twenty-four inches diameter. The pumps to be single suction, and with interior lining capable of being conveniently removed when worn.

Each pump to be actuated by a horizontal compound non-condensing engine capable of making two hundred revolutions per minute under ordinary working conditions, and developing three hundred actual horse-power with boiler pressure at one hundred and forty pounds. The piston rod of each cylinder to be attached directly to the pump shaft. The cranks at right angles. The steam to be supplied by a battery of six boilers of the Mississippi River steamboat type.

The discharge pipe for each pump to be twenty-four inches in diameter and five hundred feet long, made up in lengths of fifty feet connected by flexible rubber hose and attached to the dredge by a horizontal swivel joint. The pipe is supported upon pontoons which will swing under the pipe and adjust themselves so as to present their narrowest dimensions to the direction of the current. The pipes to be made to discharge the material either directly astern or at right angles to the dredge.

Each pump with its suction and discharge pipe, engine and three boilers to be practically independent of the other.

Drawings.—Only general drawings of the dredge, with detailed drawings of such parts as it is desired to make standard, will be furnished to the contractor. All other working drawings shall be made by the contractor as part of the contract, and shall be submitted to the United States Engineer officer in charge for examination before the work is proceeded with. Such examination, however, shall

not relieve the contractor from any of the requirements or obligations enjoined upon him by the terms of the contract.

Contractor's Drawings, etc.—The contractor shall furnish a complete set of tracings of all working drawings used in the construction of the dredge, and also all such patterns, duly marked, from which special parts are cast as may be designated in these specifications. These shall be delivered to the Engineer Officer in charge before final payment is made.

Weights of Machinery, etc.—Each copy of the proposal to have attached to it a general specification of the engines and machinery proposed to be furnished, and also a list of the weights of the same.

Main Dredging Pumps.—The dredge will be supplied with two main dredging pumps of the Single Suction Centrifugal type, placed in the hull as shown upon the drawings on sheet No. 1. They will be rights and lefts with respect to each other. Each pump will have twenty inch suction and discharge openings. The discharge to be under. The shell to be approximately forty-eight inches in diameter and twenty-eight inches deep, inside measurements. To have suitable sized manhole plate, fitted and bolted so that it can be readily removed and replaced for the purpose of examining the interior of the pump, and replacing when necessary the detachable extension plates, or wings, which form a part of the pump disc. To have front and back heads fitted with heavy cast-iron liners capable of being removed when worn. The heads separately bolted to their respective places by having their bolts placed in recesses or slots cast in the shells and head flanges, so that either of the heads can be quickly removed and replaced. Each head to have a cast iron lug with shackle and bolt for handling same.

The pump disc, or runner, to be approximately forty-eight inches diameter, and made of steel cast-iron with double rimmed flanges and three reversed curved wings or arms, and having a centre clearance into the pump of approximately the same area as the suction opening, so as to readily pass obstructions, and to avoid choking the pump as much as possible. The ends of these wings to be fitted with detachable extension wing plates, secured to their places by bolts passing through slotted holes in the same. These extension plates to be made of mild steel, and so curved as to reduce the friction of the same against the inside of the pump shell. The pump disc to be fitted with fine hammered steel shaft; inside and outside bearing bushings, as also the gland, to be of bronze. The inside bearings to be so fitted and placed as to form an oil chamber for proper lubricating.

Front head of pumps to be furnished and fitted with an outside lubricator of a suitable size and approved design; to have stop valve and fittings so arranged that a water-supply from a force pump can be connected to this oil chamber for the purpose of keeping the sand out of the bearings while in operation.

Pump to be provided with an approved adjustable thrust and rings, to be secured to the front head by substantial bolts so that the thrust may be adjusted while the pump is in operation.

Pump shaft to be directly connected by and through a split coupling and a coupling balanced fly wheel of suitable diameter and weight, to the end of the crank shaft of a double crank horizontal non-condensing compound engine. This crank to be made of the best quality of fine hammered forged steel.

Each pump to be provided with an air exhauster or primer of ample capacity, and suitably connected, with all pipes and valves necessary for the same. All pieces of the pump casing and other parts of the machinery that have to be frequently handled must be amply provided with eye bolts, lugs and shackles suitable for lifting same.

Main Engines.—Each pump to be driven by a horizontal non-condensing compound direct connected engine, capable of developing three hundred actual horse-power, at an approximate speed of two hundred revolutions per minute with boiler pressure of steam one hundred and forty pounds per square inch, and maintaining through the suction and discharge pipes the velocity necessary to carry at least twenty per cent. of sand with eighty per cent. of water under a maximum head of thirty feet. This will be regarded as the average work of the engine, to be done without over-straining the parts or heating the bearings. It must be simple in design, heavy and substantial in build, and have extra large wearing surfaces ; and be fitted up in the best possible manner and in accordance with the best practice for high velocity engines. The pump and engine must be fitted to and mounted upon a substantial cast-iron base, thoroughly bolted and aligned and supported, and fastened substantially to the hull of the dredge so as to avoid springing when working up to maximum speed. The engine will be fitted with all necessary sight-feed and other lubricators, adapted to continuous service ; also indicator cocks and connections for taking diagrams, also with all valves, cocks, pipes, steam governors, and every other appliance of approved pattern necessary for its convenient and proper operation.

Gauges, etc.—All necessary gauges and pressure indicators to be of a pattern to be approved by the Engineer Officer in charge, shall be furnished and put in place by the contractor.

Jet pumps.—With each main pump there will be a jet pump for applying water under pressure through nozzles to the sand at the entrance to the suction pipe. This pump to have two high pressure cylinders eight inches in diameter, two low pressure steam cylinders twelve inches in diameter, two water plungers, twelve inches in diameter ; all with a stroke of ten inches.

The steam cylinders to be cast on end in dry sand moulds and of special iron most suitable for the purpose. They must be of ample thickness for re-boring. The low pressure cylinder to be provided with dash relief valves to govern the cushion and length of stroke. The packing between high and low pressure cylinders to consist of a long metallic sleeve with a flange on one end. The sleeve to be carefully fitted to the rod, and each side of the flange to be ground to the faces of the plates secured to the intermediate head.

Steam valves to be of slide valve pattern, working over ports that will be of ample area to insure the proper admission and exhaust of steam without undue loss by friction. To be operated by means of direct lever connections.

Each of the steam pistons to be fitted with an adjustable packing ring expanded by a spring. The piston rods to be of Tobin bronze, and of sufficient size and stiffness to transmit the power from steam to water end of pump without tremor ; and to extend directly and rigidly from steam pistons to water plungers.

A connection to be provided to each of the low pressure steam cylinders so that in case of emergency when an unusually heavy water pressure is required the steam from the boilers can be used in the low pressure cylinders without regard to the high pressure cylinders.

The water plungers to be of Tobin bronze. Each to work through a set of external stuffing boxes located between the forward and rear water chambers, and to be readily packed from the outside.

The pump valves to consist of rubber discs of small diameter working under brass guards screwed into brass seats. The valves to be controlled by straight composite springs.

The steam and water ends of the pump to be connected by heavy cast-iron frames. These frames to be bolted at each end. The stuffing boxes to be cast separate from the frames or cylinders.

Every detail of the engine and pump to be built of first-class material and workmanship, and all lubricators, pipes, cocks and other accessories necessary to the proper working of the same to be supplied.

Each pump to be guaranteed to handle twelve hundred gallons of water per minute against a water pressure not exceeding sixty-five pounds when running compound and supplied with steam at one hundred and fifty pounds pressure. When using the direct steam connections, and the steam pressure mentioned above is supplied, a water pressure not exceeding one hundred and ten pounds must be maintained. Each pump to be guaranteed to withstand a working pressure as high as two hundred pounds. A safety valve must be supplied with each pump to relieve the strain when pressure exceeding this amount is applied.

These pumps are to be located with their suction and discharge pipes substantially as shown in the drawing on sheets Nos. 1 and 4. The suction pipes to be ten inches in diameter and to take water from the side of the dredge near the bottom. The mouth to be protected by a screen to prevent drift from passing through pumps and into the nozzles. A straight way valve of the same diameter as the suction pipe to be placed as near the inlet as practicable, and a steam or water connection provided for clearing any drift that may lodge upon the screen.

Water Jets and Pipes.—The discharge pipe of each jet pump to be eight inches in diameter. To pass from the pump, as shown in the drawing, through the forward end of the dredge. To be continued at this point with a short piece of rubber hose of the same diameter, about nine feet in length ; thence by pipe

along down the underside of the main suction pipe to a point near the end of the same where it separates into three branches and finally terminates under the main suction nozzle in three bronze nozzles one and one-half inches in diameter. This discharge pipe to be fastened firmly to the hull and to the main suction pipe, as shown in detail in the drawings on sheet No. 5, and to be made of lap welded steel tubing. All patterns of castings used on the discharge pipes to become the property of the United States.

Boilers.—Steam to be supplied by six boilers of the Mississippi River Steamboat type, each forty-eight inches in diameter and twenty-eight feet long and containing five flues each eleven inches in diameter. These boilers to be made of marine steel of sixty thousand pounds tensile strength, and in strict accordance with the requirements of the rules prescribed by the "Board of Supervising Inspectors" for a working pressure of one hundred and forty pounds per square inch. The boilers to be arranged in two batteries, and each battery to have one steam drum thirty inches in diameter, and two mud drums fifteen inches in diameter, properly rivetted to their places. All holes in shells to be drilled and all seams to be double rivetted. All furnace fronts and grates, and all sheet iron casings to be furnished, and boilers to be bricked in, in a thoroughly first-class manner. It is desired that these batteries shall be so arranged that either one can be fired and steam taken therefrom for any purpose required upon the dredge, without reference to the other, or they may both be used as one. Suitable pipes, valves, etc., must be provided for accomplishing this purpose. All the usual and necessary fittings, pipes and valves to be supplied and arranged in most convenient positions for working same. Smoke stacks to be forty-two inches diameter and about seventy feet high, and supplied with all necessary casings, umbrellas and wire-rope guys. Before the dredge is submitted to the efficiency test, the boilers and all the main connections shall undergo the usual hydrostatic test to a pressure of two hundred and ten pounds per square inch, to the satisfaction of the Engineer Officer in charge, or such agent as he shall appoint for the purpose.

Feed Pumps.—Two feed pumps with outside packed plungers, which shall not be less than four and one-half inches diameter and ten-inch stroke to be supplied, each capable of delivering sixty gallons per minute at average working speed. These pumps to be of the Worthington type pressure pattern, or some other of equal capacity and endurance, to be approved by the Engineer Officer in charge. They are to be fitted with all necessary lubricators, valves and pipe connections.

Heaters.—A feed-water heater of some make to be approved by the Engineer Officer in charge, and of ample capacity to supply the boilers, is to be placed over each feed pump, as shown in the drawing on sheet No. 1, and fitted with all necessary connections.

Pump Well.—The pump well to be five feet long, two feet six inches wide, and three feet six inches high, made of steel plate three-sixteenths inch thick, with a band of two-inch angle bar iron around the top edge, the flange of this angle bar, to which the cover is to be fastened, to be perforated with eleven 16-inch

holes, six inches pitch. A removable semicylindrical screen one and one-half feet radius, of heavy iron about ¼ inch mesh to be fitted in the well. The supply pipe to be six inches diameter, and to have a single gate valve placed as near the intake as practicable, and the mouth protected by a bar screen. A 1¼-inch steam connection to be provided to clear away drift, etc., from the screen. A 1½ inch brass screen plug to be fitted to bottom of inside for washing out.

Fire Pump.—The fire pump to be of the outside packed plunger pattern of some make approved by the Engineer Officer in charge, and to have a capacity of at least one hundred gallons per minute. The main pipe line to be placed in convenient positions and have hose connections on each side of dredge on each deck. Connections also to be made to sand chambers of main pump stuffing boxes, to spud anchor, to water tank on upper deck, and to fire stand pipes. Steam connections to be made from both main and auxiliary boilers. Four lengths, each fifty feet long, of 2½ inch diameter best 4-ply rubber hose, with all necessary couplings, caps, nozzles and valves to be supplied; also hose keys with chains attached, and suitable racks for hose. A suitable safety valve to relieve excessive strain upon this pump when nozzles are suddenly closed, to be supplied and attached to the discharge pipe near the pump.

Hull.—The hull to be built of steel throughout, as shown on drawings on sheets Nos. 3 and 4, and in accordance with the rules of the American Shipmasters' Association, in so far as such rules are applicable. Hull to be 160 feet long, 40 feet beam, and 6 feet 6 inches deep, moulded dimensions. The opening or well at the bow, in which the suction pipes are placed, to be 24 feet wide at forward end, 18 feet at after end, by 34 feet long; and the two projecting ends thus formed to be strongly tied together by a box girder 36 inches wide by 30 inches deep. The junction of this girder with sides of well to be reinforced with angles and cover plates. Two angles to be rivetted along the front of this girder, perforated with holes to receive screen bars made of 3-inch double extra heavy pipe, and spaced 4 inches apart in the clear, and to hang 9 inches below the surface of the water. The hull to be open in the parts occupied by the pumping machinery and the boilers, and to be decked over the remaining parts with steel plate. The after deck to project 12 inches beyond the stern of the hull for its entire width, and the guard thus formed to be strongly connected to hull by ten gussets of 5-16 inch plate, and to have a fender plate 10 inches wide and ⅜ inch thick rivetted on outside edge with a 3 inch steel angle. The hull to be provided with two sheer angles 3 inches by 3 inches, 7·2 lbs. per foot, on either side running the full length of hull and firmly rivetted to same. Fender strakes of white oak, 6 inches wide and 10 inches deep, to be neatly fitted to sheer angles at sides and stern, as shown on drawings, and secured to hull by ¾ inch button-head bolts at about 15 inch pitch, staggered. These fender strakes to be laid on a thickness of hair felt throughout their length, the hull having previously received two coats of strictly pure red lead and oil; and the bent portion of fender strakes at the corners of the after guard to be protected with iron straps 7 inches wide and ¾ inch

thick, secured by $\frac{3}{4}$ inch countersunk bolts. The floor beams to be of 12-inch channels, 40 feet long, weighing 25 lbs. per foot, except at sides of well where they will be 12 inches by 20 lbs. Side frames to be of 3 inch by 4 inch angle bars, 11 lbs. per foot, rivetted to web of floor beams, and further secured to same by gussets, and connected in like manner to deck beams, as shown. Side frames to be spaced with same pitch as floor beams, namely : 24 inches in the compartment containing main pumping machinery, and 30 inches apart throughout remainder of hull, as shown on drawings. Ten keelsons of 15-inch steel I beams, all to run fore and aft ; the two outboard keelsons to weigh 55 lbs. per foot, and the eight intermediate keelsons 45 lbs. per foot. Keelsons to be in as long pieces as practicable, connected by double butt straps of $\frac{3}{8}$ inch plate flanged to fit accurately between flanges of I beams, and treble rivetted with $\frac{3}{4}$ inch rivets. The butts of consecutive keelsons to be about six floor beam spaces apart, and each keelson to be attached to each floor beam by two $\frac{3}{4}$ inch diameter rivets. Each of two middle keelsons to be stiffened throughout its entire length by a continuous line of intercostal plates between it and the bottom plating. These intercostals to be of pressed plates $\frac{5}{16}$ inch thick, and to accurately fit the spaces between the keelsons and bottom plates and floor beams, and are to be rivetted to the lower flanges of the middle keelsons, and to the webs and flanges of the floor beams, and to the middle strake of the bottom plating, with $\frac{3}{4}$ inch rivets, with a pitch of 3 inches. Limber holes in bottom of intercostal plates under middle keelsons.

Outside plating of hull to be not less than six frame spaces in length. Longitudinal seams may be lapped, transverse seams must be butted. The butts of adjoining strakes to have a shift of not less than two frame spaces, and those of alternate strakes a shift of not less than one frame space. The centre strake of bottom plating to be $\frac{3}{8}$ inch thick, and all other bottom strakes to be $\frac{5}{16}$ inch thick. The upper strake of side plating to be $\frac{3}{8}$ inch thick, reinforced at the extremities of all athwartship bulkheads with doubling plates $\frac{5}{16}$ inch thick, as indicated in drawings on sheet No. 3. The lower strake of side plating to be $\frac{5}{16}$ inch thick. The bottom plating to be continued up to deck line at stern to form end plating ; and also at after end of well as far up as the pipe frame strake; which will be a single plate $\frac{5}{8}$ inch thick. The bow end plates and rake to be $\frac{5}{8}$ inch thick, and all side plates in well to be $\frac{5}{16}$ inch thick.

The butts of all outside plating to be planed or chipped fair and fitted close, metal to metal, and all shearing to be done from the faying surface of plates. The butts of bottom plates to be treble rivetted and to have single butt straps $10\frac{5}{8}$ inches wide and $\frac{1}{8}$ inch thicker than the plates which they connect. The butts of side plates to be double rivetted and to have single butt straps $7\frac{1}{4}$ inches wide, and $\frac{1}{8}$ inch thicker than the plates which they connect. All butt straps to be in one piece and to entirely cover the seams over which they are fitted. The fibre of double and treble rivetted butt straps must be in the same direction as the plates to which they are secured. All longitudinal seams of outside plating to be single rivetted lap $2\frac{1}{4}$ inches wide. Solid liners in one length

to be fitted at every frame, between frames and outside strakes of outside plating. Liners to be the width of the flange of the frame to which they are fitted, and to be carefully fitted so as to fill the entire space between the edges of the inside strakes. All butt straps to be on inside of hull, and all outside plating rivets to be countersunk on outside. All seams intended to be watertight must be thoroughly caulked.

The deck plating to be $\frac{1}{4}$ inch thick, except at sides of boiler and engine hatches, where it must be 5-16 inch thick. All seams to be double rivetted, butt jointed, with single straps on under side $7\frac{1}{4}$ inches wide and $\frac{1}{16}$ inch thicker than the plates they connect, with rivets to be countersunk into deck plate. The deck to be further stiffened or supported from below at points carrying the heels of stanchions, or braces, or shop machinery; also at the points of attachments of capstans, timberheads, chocks, kevels snatchblocks, and guys.

The through-deck beams under machinery on forward deck to be of 6-inch bulb angles, 12·3 lbs.; all other through-deck beams to be 5-inch bulb angles, 10 lbs. Deck beams at side of well to be 5-inch bulb angles, 10 lbs., and the short deck beams at sides of engine and boiler hatches to be 3-inch angles, bars, 6 lbs. Suitable supporting steel stanchions resting on keelsons will be placed under all deckbeams, and the unsupported span of any deckbeam to be not more than 7 feet 4 inches.

The hull to be divided into eleven water-tight compartments by fore and aft and athwartship bulkheads, as shown on drawing No. 3. Bulkheads to be $\frac{1}{4}$ inch thick, stiffened with $2\frac{1}{2}$ inch angle bars, and to have single rivetted seams. The intercostals for floor beams and keelsons, for all water-tight bulkheads, to be of pressed plates $\frac{5}{16}$ inch thick. The bow plating to which suction pipe frame is attached to be stiffened with tie plates and braces to false bulkhead, as shown in drawing on sheet No. 4. All holes cut in bulkheads for suction, discharge or other pipes, to be efficiently compensated where necessary, and made thoroughly water-tight.

The engine room to be floored with $\frac{3}{16}$ inch steel plates butt jointed on keelsons, closely fitted to discharge pipe and stiffened with light 2-inch angle bars running athwartship between keelsons, with a pitch of 15 inches and rivetted to under side of floor plating with $\frac{3}{8}$ inch rivets. All rivets in floor plating to be countersunk into plating. All foundation plates, stiffening plates and angles necessary for pumps and machinery, to be built in hull as required; also all platforms and steps or ladders needed for the proper fitting out and completion of dredge to be supplied and fixed in place. The floor in the coal room and stoke-hold to extend between longitudinal bulkheads, and to be carried on athwartship false floor beams, of 20·5 lbs. 12-inch channel bars, 33 feet long, spaced with a pitch of 30 inches, resting upon the keelsons. The webs and lower flanges to be cut away at the ends of these channel bars in order to clear 24-inch discharge pipes, and the ends of upper flanges of channels to be secured to longitudinal bulkheads by means of angle clips. The floor plating to be $\frac{3}{16}$ inch thick and butt jointed on above-

described false floor beams, and to be rivetted and stiffened in the same manner as prescribed for engine room floor. The boilers to be carried upon four boiler beams, of 12 inch channels, 25 lbs. per foot, two under front of boiler, and two under after mud drums, as shown on drawings.

A suitable well for spud anchor to be built in forward part of hull, as shown in drawings on sheets Nos. 1 and 4.

The "A" frame from which suction pipes are suspended, to be built of I beams and angles, the whole to rest on keelsons of hull and be securely rivetted to same, all as shown on drawings on sheets Nos. 1 and 7.

Rivets to be of soft steel and $\frac{5}{8}$ inch diameter throughout the hull, except where otherwise specified or noted on drawings, or where the nature of the work requires a different size. The rivets in seams or laps of outside plating to be spaced longitudinally not more than $2\frac{1}{2}$ inches centre to centre, and rivets in seams or laps of all internal water-tight work to be spaced not more than $2\frac{3}{4}$ inches centres. All double rivetting, including butts, to be chain fashion, except where otherwise noted on drawings, the distance from centre to centre between the rows to be $1\frac{5}{8}$ inches. No rivet to be nearer the seam, butt, or edge of a plate or angle bar than its diameter. Spacing of rivets in beam knees to be from $2\frac{3}{4}$ inches to $3\frac{1}{8}$ inches centres, but no beam knee to be secured to its frame or beam with less than four rivets. Rivets for securing outside plating to floors and frames, stiffening angle bars to bulkheads, and all work where angle bars do not require to be caulked, to be spaced not more than 5 inches centres. Angle bar clips and splice pieces to have not less than four rivets in each flange. Rivet holes to be regularly spaced and punched from faying surfaces and to be opposite each other in adjoining surfaces. Heavy drifting not to be resorted to. Holes not punched fair to be drilled or reamed fair and a size of rivet to fit the hole to be used. Countersinks to be not less in depth than three-fourths the thickness of plate or angle bar countersunk. Rivets to completely fill their respective holes, and the heads to be laid up in outside plating and all other water-tight work ; the points of rivets when finished to completely fill the countersinks and be slightly convex or flush with their respective plates or angle bars.

The hull to have all necessary hatchways, with suitable deck rings or coamings, gratings and covers ; also convenient ash chutes in stoke-hold, with doors for same. The hull to be further provided with all necessary bitts, fair-leads, and cleats, secured in a good and substantial manner, and also two davits at the stern to lift the coupling hose of pipe line. The water-tight compartments to be fitted with 3-inch bilge syphons ; two in each of the five large compartments and one in each of the compartments at sides of well and engine and boiler rooms, sixteen in all. The discharge pipes for syphons to be attached to outside plating by flanges and bolts, and all valves to be placed so as to be easily accessible from deck. All other pipes, such as water-closet pipes, blow-off pipes, overflow and drain pipes, etc., discharging through sides of dredge, must be attached to plating by flanges either bolted or rivetted.

Suction Pipes.—There will be a suction pipe for each main pump having an inside diameter of twenty inches. It will leave the pump by a reverse curve, pass out through the hull at the pipe frame strake and by a radial joint down through the suction well, and terminate with a nozzle or suction head ten feet wide and twenty inches high, inside measurements, as shown upon the drawings on sheets Nos. 1, 5 and 6. The reverse curve, the radial joint, flanges on the pipe, and the junction piece between pipe and suction head to be steel castings, the other parts of the pipe to be of plate steel $\frac{1}{4}$ inch thick. The suction pipe and suction head to be smooth on the inside, the pieces put together with outside butt straps, rivets to be countersunk on inside. All seams to butt with chipped or planed edges so as to form a metal contact. Butt straps to be $5\frac{1}{2}$ inches wide and $\frac{5}{16}$ inch thick. The flanges on the pipe outside the hull to have landing on the pipe sufficient for double rivetting. A 3-inch × 4-inch 11-lb. angle iron to be rivetted to the top and bottom of the pipe to attach bracing.

Suction head to be curved, radius of centre 13 feet, to be made of steel plate $\frac{3}{8}$ inch thick. The junction piece which joins the suction head to the pipe to be steel casting with flanges well bracketed, and to have at least 7 inches of landing for plates with double row of rivets. Six screen bars or lobes, made of steel plate $\frac{1}{4}$ inch thick to be placed within the suction head. Two $3\frac{1}{2}$-inch angle irons 13·6 lbs. to be placed on top side of head, to which lugs for bracing and sling chains are to be rivetted. All these and other parts to be made in conformity with drawings shown on sheets Nos. 5 and 6. Stiffening and bracing parts to be provided as shown on the same drawings. There is to be provided a bracket hanger of ample strength and suitable design for the support of the inner ends of the diagonal bracing of the two pipes. This to be steel casting and firmly attached to the hull of the dredge at the pipe-frame strake, as shown on drawing. The straining frames shown on drawing No. 7 to be made to fit on suction heads and to work in pinning brackets, which last are to be steel castings rivetted on bow girder.

Radial Joints.—Each radial joint for suction pipes to consist of three parts. The "stuffing box" to be a steel casting with heavy flange to bolt to hull of dredge, and lugs for carrying suction frame, and from which the frame will radiate, and to be fitted with rubber packing ring, etc., as shown on drawing No. 6. The "radial pipe" which slides in above stuffing box to be steel casting 20 inches diameter inside and machine finished outside. The "flange piece," which is rivetted to suction pipes, to be a steel casting and have heavy lugs fitting into those on stuffing box, all connected by a finished steel pin 3 inches diameter. All parts of the radial joints must be of ample strength to take all strains to which they may be subjected, and must be thoroughly well fitted, and great care must be exercised in fixing them truly in line on hull of dredge. All radial joints to have sufficient range to admit of dredging in 15 feet depth of water, and to raise jet nozzles above bow girder, and to be so arranged that when dredging in 6 feet of water the end of radial pipe shall offer no obstruction to the flow of water to pump.

The patterns from which the reverse curves in the suction pipes, the radial joints, and the junction piece between pipes and suction heads are cast to be the property of the United States.

Suitable provision to be made where the suction or any other pipe to be used in the dredge, passes through a water-tight bulkhead to insure that no leakage shall take place.

Discharge Pipes and Pontoons.—There will be one discharge pipe for each main pump. All straight portions to be made of tank steel $\frac{1}{4}$ inch thick. Curved portions and flanges to be steel castings. The discharge opening of the pump being twenty inches diameter, the discharge pipe will be enlarged at the pump by a short piece of straight pipe to twenty-four inches diameter, thence to make a quarter turn with a radius of 4 feet 9 inches, and extend down and directly out through the stern of the dredge, resting on the floor beams as shown on the drawings on sheets Nos. 1 and 4.

At the stern of the dredge there is to be in each pipe a reverse curve swivel joint, by means of which the pipe beyond the dredge will be slightly raised, and can be changed in direction through an angle of 180 degrees. Details of this joint are shown in drawings upon sheet No. 6. Near the stern of the dredge and inside there shall be provided in each pipe a suitable hand hole for introducing the suction pipe of a small pump for the purpose of clearing the pipe of water. On the outside of the dredge the discharge pipes to be in lengths of 24 feet, connected by flanges, each two of such lengths to be connected by a coupling and piece of flexible rubber hose 3 feet 8 inches long. The pipes to be supported every twenty-five feet upon steel pontoons so arranged that they may swing under the pipe and present their narrowest dimension to the direction of the current. The pipe to be connected to the dredge by a piece of flexible rubber hose 5 feet 8 inches long. Each discharge pipe to have a length of five hundred feet and terminate with a baffle plate for the purpose of steadying the pipe line while material is going through it. The pontoons to be made of tank steel $\frac{5}{16}$ inch thick, rivetted to suitable frames of angle iron, and provided with a chair for holding the pipe, and king bolts and plates; also manholes, siphonholes, kevels, ring bolts, clevises, rudders and other appliances for towing and using them. All details of construction of the discharge pipes and pontoons, and the manner in which they are to be used, are shown on the drawings on sheet No. 8. The patterns from which the swivel joints and the curved portions of the discharge pipes are made to become the property of the United States. All seams of the pontoons must be thoroughly caulked and made perfectly water-tight.

The discharge pipes to be made of tank or soft steel, $\frac{1}{4}$ inch thick, twenty-four inches interior diameter, with steel casting flanges, both of first class quality and free from blemishes of every character. Joints to be abutting, with surfaces planed or chipped so as to form metallic contact, and with outside strap pieces 3 inches wide and staggered rivets. Rivets to be $1\frac{1}{2}$ inches between centres and countersunk on inside. Inside surface to be smooth.

Flanges to be as shown on drawings, with faced surfaces at right angles to axis of pipe. Bolt holes spaced and drilled in accordance with usual rules. Pipes to be perfectly water-tight under a pressure of seventy-five pounds per square inch.

Rubber Hose.—The flexible rubber hose to be supplied for the discharge pipes to be 8-ply best Para rubber, with interior lining of pure rubber ¼ inch thick, and ends capped with rubber so that cotton may not be exposed. Interior diameter to be twenty-five inches. All to be made in the most perfect manner and plies warranted not to separate. Hose to be attached to ends of pipe sections and to swivel joints with wrought iron bands, as shown in drawings.

Hand Winches.—Four hand winches with wooden platforms, on which to place the same, to be provided for the purpose of handling the lines with which the pipes are to be deflected.

Painting.—All iron surfaces must be cleaned, scales and all traces of oxidation removed before painting is begun. The hull, discharge and suction pipes and jet pipes, with all bracings and iron work connected therewith, and pontoons, to receive two coats of strictly pure red lead and oil, both inside and out, and one coat, the last, of such color as may be designated. Pipes need not be painted on the inside. Faced surfaces of turning plates on pontoons to be preserved with a coating of white lead and tallow. The machinery to be painted three coats of good oil paint of such colour as may be selected, the last coat to be put on after all preliminary trials have been made, before the dredge is received by the Government. It is understood that no part of the dredge, or any of its appurtenances or appliances, is to receive any paint or coating substance of any kind until after the contractor has notified the inspectors that such part is ready for painting and received permission to proceed with this work.

Suspension Tackle.—The lower end of the suction pipes to be suspended from "A" frame at bow of dredge by a 1¼-inch manilla rope of best quality, reeved through double and triple blocks of suitable size and strength, the rope to lead to winch heads of bow-winches. The connection to suction heads to be made by 1-inch sling chains 10 feet long. All tackle to be of ample strength for the purpose intended, and of best quality and workmanship.

Bow Winches.—Two bow winches to be placed near sides of well on forward deck, as shown on drawings on sheet No. 1, for operating the forward or feed movement of dredge. These winches to have double engines geared in such a ratio that they will wind up at speeds varying from ¼ inch to 7 inches per second, with drums at least 42 inches diameter and of sufficient length to hold 1,200 feet of ¾-inch diameter wire rope, in two lays, and must be fitted with clutches and brakes, so that drums may be overhauled and lines paid out quickly. Engines to have reversing motion and be furnished with all necessary lubricators, valves, pipes and drains ; also, to have winch-heads on ends of main shaft for the purpose of hoisting and lowering suction heads, and doing other work. Gearing to be so arranged that drums need not always revolve when main shaft revolves.

Spud Anchor.—The spud anchor to be of oak, 22 inches square and 36 feet long, fitted with cast-iron shoe and cap, and arranged to work in a well provided for that purpose at bow of dredge. The spud to be fitted with hydraulic power for sinking, as shown in drawings on sheets Nos. 1 and 7, and to be connected to fire pipe line by 2½-inch diameter rubber hose. To raise the spud there will be two mild steel bands, each 5 inches wide and 1⅜ inches thick provided with lugs, placed around the spud. These will be loose so as to slide up and down the spud freely. By taking hold of a lug on one side the band will bind to the spud and permit it to be raised when sufficient power is applied. Suitable arrangements will be made for applying this power through blocks and fall, as shown on drawing on sheet No. 1. The falls will lead through snatch blocks attached to eye bolts to the winch heads of the bow winches. Where the spud goes through the cabin deck there is to be provided four guide rollers, resting upon a cast-iron frame suitably fastened to said deck. All blocks, lines and fastenings must be of sufficient strength and proper design for accomplishing the purpose, without overstrain, for which they were intended.

Auxiliary Boiler.—A vertical boiler, 42 inches diameter and 8 feet high with submerged tubes, to be placed in boiler room and connected with electric light engine, fire pump and shop engine, and furnished with all usual fittings, valves and connections. This boiler to be made in accordance with the rules prescribed by the "Board of Supervising Inspectors" for a working pressure of 140 lbs. per square inch.

Steam Capstans.—Four steam capstans for handling side lines to be provided and placed as indicated on drawing on sheet No. 1. They must be of some make approved by the Engineer Officer in charge, with double engines having cylinders not less than 6 inches diameter and 8 inches stroke, and fitted with all pipes and valves and levers, arranged in such a manner as to be conveniently operated from deck. The engines to be placed in hold of dredge.

Operating Levers, Signals and Gauges.—The dredge must be provided with all necessary levers, signals and gauges conveniently placed, for the efficient and safe operation of all its parts.

Pipes, Valves, etc.—All the pipes, valves and fittings necessary to complete the dredge and put it in thorough working order must be supplied, of the very best quality and make approved by the Engineer Officer in charge. All small valves, up to and including 2½ inches in diameter, to be of brass, heavy pattern, and all valves above 2½ inches diameter to be brass mounted and of heavy pattern. Steam and feed pipes to be made and fitted in accordance with the requirements of the rules of the "Board of Supervising Inspectors," special attention being paid to making provision for the expansion and draining of said pipes. All main steam pipes and principal connections to be covered with good non-conducting material to be approved by the Engineer Officer in charge.

Wire and Other Ropes, Blocks, etc.—The following ropes to be supplied: Two bow lines of ¾ inch diameter wire rope, 19 wires to the strand, each 1,200 feet

long, to be selected or approved by the Engineer Officer in charge. Four breast lines 1¼ inch diameter, best quality manilla bolt rope, each 600 feet long. Two lines 1¼ inch diameter, best quality manilla bolt rope, for hoisting suction heads, lengths as may be required, and such other lines with blocks and tackle as may be necessary for the efficient working of the dredge.

Spare Parts.—One runner or disc, with shaft, for each main pump of same material as original runner and shaft. One set bronze glands for each main pump. One complete set liners for each main pump. One set grate bars for each battery of boilers.

Mooring Piles.—The dredge will be moored in position by bow and breast lines which will be attached to iron piles ; the bow lines of ¾ inch steel rope passing over snatch blocks on " A " frame to bow winches, and the breast lines of 1¼ inch diameter, best manilla bolt rope going to capstans. There will be six 10-inch piles and ten 7-inch piles required, made of wrought-iron tubing, put together as per drawing on sheet No. 9, and fitted with all clamps and hose connections ready for work.

Electric Light Plant.—This plant will consist of an engine, dynamo, belt, two 2,000 c. p. arc lights ; one 4,000 c. p. focussing head-light with reflector ; seventy-five 16 c. p. incandescent lamps ; a hardwood switchboard with necessary switches, lead and current wires, fuse plugs, ammeter, voltmeter, rheostat, and all other appliances necessary for a complete outfit. All to be approved by the Engineer Officer in charge.

Engine.—This must be a horizontal single expansion, double acting, self-oiling, automatically governed engine, with a 7-inch by 10-inch jacketed cylinder, or equivalent, designed to work in a satisfactory manner, with a boiler pressure of 165 lbs. per square inch, and provided with a " Foster " reducing valve to give a uniform and satisfactory working pressure. The driving pulleys to be 42 inches diameter, 8½ inches face, with the governor adjusted for 200 to 225 revolutions per minute with any load up to 25 h. p. The engine shall be bolted to a sub-base of suitable pattern ; both surfaces of the joint being surfaced in a workmanlike manner and held by not less than four steel dowel pins, each ½ inch diameter. All necessary oil cups, pet cocks, wrenches, etc., must accompany the engine, and necessary foundation, exhaust pipes and steam pipes to connect with each battery and donkey boiler, furnished and placed as directed.

Dynamo.—The dynamo will be a direct current, constant potential multi-polar 110 volt machine of the " Western Electric " pattern, of not less than 9 k. w. capacity at 850 revolutions per minute, with a pulley of such size as to give the normal speed with a 42 inch driving pulley making 200 revolutions per minute, free from sparking, and automatically regulated so that any or all of the load can be turned on or off while running at normal speed without disturbing the voltage or heating any part of the machine. With self-oiling attachments and oil gauges, mounted on a sliding base and foundation, to be approved by the Engineer Officer in charge.

Belt.—The belt must be of the best grade of double leather, oil finished, 6 inches wide, and of sufficient length to prevent slipping.

Lights.—The head-light must be a focussing arc light with reflector of the "brush" pattern of 4,000 c. p., burning and feeding properly with a constant potential current of 20 amperes. It must have a dead resistance in the circuit, that with the lamp will take up the 110 volts of the dynamo without danger from fire. Bracket will be furnished of design to be approved and placed as directed. The arc lights must be "Adams-Bagnell" constant potential lamps of 2,000 c. p., burning and feeding properly with current of 10 amperes. They will each be put up in an independent circuit, and must have a dead resistance, that, with the lamp, will take up the whole voltage without danger from fire. They must be furnished with clear glass globes, supported without the use of wire netting, metal weather hoods, and automatic stops or cut-outs. The booms for these lights will be furnished of pattern and located as directed. Incandescent lamps must all be 16 c. p., 110 volts, lamps with Edison key sockets of standard size.

Wiring.—The wiring will be located on the dredge as may be directed by the Engineer Officer in charge. The diameter of wires, and wiring and insulation, must be in accordance with the requirements of the St. Louis Board of Underwriters. Weather-proof insulation must be used for exposed places, and rubber insulation for inside work. All wires well straightened and put up in a most workmanlike manner.

Switch Board and Attachments.—A neat hardwood switch board must be furnished and put up, containing all the necessary switches for controlling the currents of all the lights. The dynamo leads will include in their circuits a voltmeter and ammeter of the "Weston" type, of suitable range, reading single volts and amperes respectively, which must be suitably mounted on the switch board. All of the above outfit must be of the latest pattern and put up in the most workmanlike manner, each part located as shown by drawings, or as directed, and made to work in manner satisfactory to the Engineer Officer in charge.

An electric signal call-bell system, comprising 1 annunciator of 4 indications; not more than 6 other bells, or "buzzers"; 1 battery of 4 Le Clanche disc cells; push buttons of plain bronze, and necessary wiring with suitable insulated copper wire, will be established. All articles to be of design and sizes to be approved by the Engineer Officer in charge, and work to be done in the most approved manner.

BOILER DECK FRAME AND LOWER DECK HOUSE.

Divisions of lower deck to consist of engine room, fire and coal room, boiler room, machine shop, wash room and water closets for crew, and ice compartment, all formed by bulkheads, and of the sizes as shown on the drawings on sheet No. 1.

Material.—All lumber used in the construction to be the best clear and seasoned, planed both sides and edges, of the sizes specified after being dressed, and of the kinds as hereinafter described.

Frame.—Main stanchions, 4 inches by 4 inches, white oak ; intermediate stanchions, 1 inch by 3¼ inches, white pine ; main clamps, 1¾ inches by 12 inches, white pine ; inside clamps, 1¾ inches by 5 inches, white oak ; main ridgepoles, 4 inches by 6 inches, yellow pine ; centre ridgepole, 4 inches by 6 inches, yellow pine ; ridgepole stanchions to be formed of two T-bars, 5 inches by 3 inches, flat parts rivetted together with a tenon formed on top, fore and aft, 3 inches by 1 inch ; carlines, 1½ inches by 6 inches, white pine ; boiler deck facing, 1 inch by 5 inches, white oak ; nosing, ⅞ inch by 5 inches, white oak ; waterway, 1 inch by 2¼ inches, white oak.

Construction.—Height at top of clamps, 10 feet 9 inches from main deck.

Main stanchions, at the sides of open part of hull, to be fastened at the heels with three screw-bolts, of ½ inch iron, to 4-inch by 4-inch angle bars four feet long, weighing 9·80 lbs. per foot, angle bars to be rivetted to hull bulkhead and extending two feet above main deck. All other stanchions to be fastened at the heels with one screw-bolt of ½-inch iron to angle clips, 4 inches by 6 inches, weighing 12·30 lbs. per foot, rivetted to main deck. Main stanchions to be spaced as shown on the drawings, and the spaces between to be filled with intermediate stanchions spaced on an average of 16 inches between centres, fastened at the heels to an oak sill 3¼ inches by 3 inches, the ends of same gained into main stanchions ¼ inch, and the sill set 1 inch above main deck.

Main clamps outside to be let into heads of main stanchions ¾ inch, inside clamp fastened to face of stanchions at the underside of carlines, and the space between clamps filled at the back of intermediate stanchions. The top of openings for doors to be framed with 4-inch by 4-inch oak and the space above filled with intermediate stanchions and the openings cased with white pine. Window frames to be of 1½ inch white pine, with framing to suit the same. Carlines to be in two lengths, spaced 16 inches between centres, let down flush with top of main clamps, the inside ends of carlines to lap three feet over each side of centre ridgepole. Laps nailed and screwbolted together with ½ inch bolts, nailed at main ridgepole and clamps, and the projection from outside of main cabin to end of guards, diminished 1 inch and finished with facing, nosing, and a waterway on deck, of the sizes and material as hereinbefore described. Main ridgepole to be placed under a direct line of the skylight stanchions of main cabin and supported by stanchions of T-bars, as hereinbefore described, the heels of stanchions screwbolted with ½ inch bolts to two angle clips 4 inches by 6 inches, rivetted to deck of hull and otherwise suitably placed, as shown on the drawings. Ridgepoles where not supported by stanchions and where the spans are more than 10 feet between stanchions, are to be supported by king-posts of 4-inch by 4-inch yellow pine, extending 30 inches below ridgepoles and trussed with chains of ¾ inch round iron extending out to sides through heads of main stanchions and through main clamp, fastened at clamp with nut and plate washer. The chains at the intersection with king-posts to be flattened into a plate ¾ inch thick by 3½ inches wide, and each chain provided with two turnbuckles of ¾ inch

round iron. Chains to be connected over the heads of the T-bar stanchions with shackles and pins of $\frac{3}{4}$ inch round iron, and the inside clamp at the intersection with chain to be reinforced with oak battens $1\frac{1}{2}$ inch thick by 5 inches wide extending over not less than three spaces of carlines and let up into carlines $\frac{1}{2}$ inch, and well nailed to carlines.

Boiler deck to be laid with tongued and grooved white pine $\frac{7}{8}$ inch thick and not to exceed 5 inches in width, secret and double nailed to carlines, and that part that forms the guard outside of main cabin to have the tongues and grooves painted with white lead before being laid, sides and ends to be covered with tongue and grooved white pine $\frac{7}{8}$ inch thick, beaded one side, secret and double nailed to all stanchions, sides laid fore and aft, ends laid vertical, and the nail heads punched. To be openings for doors and windows, and of the sizes as shown on the drawings.

End and partition bulkheads to be constructed with stringers of 2-inch by 4-inch white pine, let into stanchions at each end $\frac{1}{4}$ inch, four stringers in each space, and covered with tongue and grooved white pine $\frac{7}{8}$ inch thick, laid vertical and secret and double nailed to stringers. The forward bulkhead to be constructed in folding sections of suitable lengths, and provided with hinges, etc., for operating and holding in place.

The under side of clamp alongside of boiler room to be spaced as shown on drawings, and each space filled with pine slats, $\frac{7}{8}$ inch by 4 inches.

End projections of boiler deck to be supported by 4-inch by 4-inch yellow pine brackets, of the design as shown on drawings, to be five brackets at each end, and brackets fastened to stanchions with $\frac{1}{2}$ inch iron button-head screw bolts. The bottom of the siding, on the sides and ends, to be finished with a $\frac{7}{8}$ inch quarter round of white pine.

Doors.—All to be oak-battened and sliding, except door to the crew's, closet and the crew's wash room, hung at the top with the best loose axle barn door hangers, to roll on iron rails at top, bolted to sides with screw-bolts, and to have sash screwed to face of door, where shown on the drawings. Door to crew's closet and wash room to be lower part panelled, upper part glass, as shown on the drawing.

Windows.—To be of the size and number as shown on the drawings, filled with double sash $1\frac{1}{8}$ inch thick, and fitted out with clamp fastenings for holding in any desired position. All glass to be double strength "American."

Swinging Fenders.—To be 12 on each side, of white oak, 6 inches by 12 inches, to extend from boiler deck guard to 18 inches below line of main deck all properly lashed at top to small oak kevels, screw-bolted with button-head bolts, $\frac{1}{2}$ inch through kevels, deck and a batten of oak underneath guard.

Stairs.—Those leading up to after cabin to be four feet wide, with oak treads 1 inch by 10 inches, white pine risers $\frac{7}{8}$ inch by 7 inches, ceiled underneath and on sides, 30 inches above cabin deck, with $\frac{7}{8}$ inch tongue and groove white pine, beaded on both sides, with handrail on top, and supported on three carriages of

white pine. Stairs leading up to main cabin to be 3 feet 6 inches wide, with oak treads 1 inch by 10 inches; white pine risers $\frac{7}{8}$ inch by 7 inches; ceiled underneath and on sides to top of cabin deck with tongue and groove white pine, $\frac{7}{8}$ inch thick, beaded both sides, and supported on three carriages of white pine. The opening on cabin deck guarded with a railing of brass tubing of the design as shown on the drawings. Stair entrances to have panelled doors hung with brass butt hinges, and to be of the size as shown on the drawings.

Steps.—To be three pairs, 3 feet wide, two pairs 2 feet wide, and one pair at side of engine room, all placed and of the number of steps as shown on the drawings. Treads to be of oak, each pair with two carriages formed of 3 inch by 3 inch by $\frac{1}{4}$ inch angle iron, set with the bosom of bars together and connected with short angle bars of same size with the bosom up, rivetted to carriages to receive the treads, and the treads screwbolted to same with button-head bolts of $\frac{1}{2}$ inch iron.

Railing.—To be one of gas pipe, and of the design as shown on the drawings, extending from entrance to main stairs of cabin around the open part of hull in engine room all bolted to main deck.

Ice Compartment.—To be constructed where shown on the drawings, the inside walls lined with tongue and grooved yellow pine flooring and covered with No. 22 galvanized iron, outside walls covered with tongue and groove white pine flooring, the space between wall filled with charcoal, the under side of carlines ceiled with tongue and groove white pine flooring, and the space between carlines and ceiling to be filled with charcoal, to have two doors, each in two sections and each section filled with charcoal, and the interior arranged as per details furnished, and to be drained with a 2-inch gas pipe leading down and out through hull under main deck. The deck in the bottom of ice compartment to be in the form of a pan, made of No. 12 galvanized iron, to be perfectly watertight, the edges of pan to project 6 inches up on the sides all around, and the pan to be drained with a 2-inch gas pipe leading down and out through hull under main deck.

Crew's Water Closets.—To be three in number placed as shown on the drawings, of porcelain, each fitted out with flush tanks of iron, and all of the necessary traps, ventilating pipes and appurtenances to make a complete outfitting, each to be connected with and drain into a 4-inch gas pipe leading down and out through hull under main deck. Urinals to be provided as shown on drawings.

Crew's Wash Room.—To be fitted out with six porcelain-lined iron wash bowls erected on brackets, fitted up in sections with granite or marble tops, nickel-plated trimmings, hot and cold water connections, overflow pipes and traps, all connected with and drained into a $2\frac{1}{2}$-inch gas pipe leading down and out through hull under main deck. Hot water connections to be made with boilers and cold water connections with a tank on cabin roof. The plumbing of closets and wash room to be done in the most workmanlike and sanitary manner, and the closets, bowls and urinals to be of a design as may be selected or approved by the Engineer Officer in charge.

The auxiliary boiler in coal room to be protected with three angle bars 3 inches by 3 inches, 7·2 lbs. per foot, set vertical, in the form of a triangle, extending from deck to deck, and two short bars 5 feet long, all as shown on the drawings, and covered with ¼ inch boiler iron to a height of 8 feet, with two doors opposite manholes of boiler.

Bulkhead separating engine room from coal room to be sheathed with white-pine planking 2 inches thick. Three sash of 6 lights each 10 inches by 12 inches glass, to be placed in this bulkhead for light and ventilation.

Spud Opening.—To be an opening in the boiler deck for the operating of a spud, placed, and of the size, as shown on the drawings. The frame to consist of 6 inch by 7 inch yellow pine, projecting forward and aft of lower bulkhead, fastened to boiler deck with button-head screw-bolts of ½ inch iron, the space between carlines to be filled down to spud frame, the opening outside of bulkhead supported by two stanchions and two braces of 6 inch by 6 inch yellow pine. The inside of opening to have iron rollers 3 inches in diameter set in cast iron journal boxes, and boxes screw bolted through sides of frame.

Lockers in the machine shop and engine room to be supplied as may be indicated.

Cabin.—Cabin proper to be 116 feet long and 32' feet wide, with skylight in two sections as shown on drawings on sheets Nos. 1 and 2.

The general dimensions of the cabin space and arrangement of the different compartments to be as shown upon the same drawings.

Material.—All lumber used in the construction is to be clear and thoroughly seasoned, dressed both sides and edges, and of the size specified after being dressed.

General Description.—Cabin clamps, 1⅛ inch by 7 inches white pine; upper skylight clamp, 1⅛ inch by 8 inches white pine; lower skylight clamp, 1⅛ inch by 9 inches white pine; outside cabin stanchions, 1 inch by 3½ inches poplar; inside cabin stanchions, 1¼ inch by 3 inches poplar; skylight stanchions, 1½ inch by 3 inches poplar; cabin carlines, 1 inch by 4 inches poplar; skylight carlines, 1⅜ inch by 5 inch poplar; bulkhead strips, 1 inch by 1¼ inch poplar, cabin planksheers, ⅞ inch by 3½ inches white pine; cabin panels $\frac{5}{16}$ inch white pine; cabin margins, ⅝ inch white pine; cabin roof facing, ⅞ inch by 4 inches white pine; cabin roof nosing, ⅞ inch by 4 inches white pine; skylight roof facing, ⅞ inch by 5 inches white pine; skylight roof nosing, ⅞ inch by 5 inches white pine; waterway for roofs, ⅞ inch by 2 inches white pine; cabin and skylight roofs, ⅞ inch tongued and grooved white pine, beaded on one side and double nailed to all carlines, and the edges of projections finished with a waterway of the size as specified. Crown of cabin roof 10 inches, and skylight roof to conform to same. Height of cabin at top of outside clamps, 9 feet; height of skylight at top of clamps, 12 feet 1½ inch; width between skylight clamps, 12 feet; cabin carlines spaced 16 inches between centres; skylight carlines spaced 16 inches between centres.

The cabin to be constructed according to the plans and of the materials described. All bulkheads to be of panels joined together with margins, and well nailed to the bulkhead strips. Cabin ceiling to be panelled, with an O G moulding, carlines capped on the under side, a neat plain cornice to extend the full length of skylights; the cornice in the main cabin to be finished with a scroll bracket resting on plain pilasters on each side of doors. The rooms of main cabin to have transom sash on the inside as shown on the drawings, a line of transom and skylight sash on both sides of cabin as per drawings.

Roofs of skylight and cabin to be covered with 10-oz. canvas duck 29 inches wide, "U. S. Standard," well lapped on the edges, and tacked with 10-oz. tacks about 1 inch to centres, and painted three coats of white lead and yellow ochre ground in oil, mixed in proportion of 150 pounds of white lead to 50 gallons of yellow ochre, and the last coat well sanded. Cabin roof to have an opening at each end connected with cabin deck by a ladder affixed to cabin; and an opening with cover hung on hinges in line with spud.

Guard railing as shown on drawings to extend all around cabin, composed of white pine slats or rails, filling and cap, and 2-inch by 2-inch oak stanchions. Stanchions to extend from cabin roof down and through cabin deck, and the tenon pinned under deck. Suitable flag poles, substantially placed in position, to be furnished.

Doors.—All to be of white pine $1\frac{1}{8}$ inch thick, except the forward doors of main cabin, and the after doors of after cabin, which are to be $1\frac{1}{4}$ inch thick; all to be hung with hook pin butt hinges; all inside doors to be panelled; outside doors, lower parts panelled, upper parts six lights of glass each, except forward doors of main cabin and the after doors of after cabin, which are to have nine lights of glass each; all of the sizes as specified and placed as shewn on drawings, and fitted out as described hereinafter.

Blinds.—All of white pine $1\frac{1}{8}$ inch thick, hung to all outside doors and windows, except the forward doors of main cabin and the after doors of after cabin; furnished with all of the necessary fastenings.

Window, transom and skylight sash to be of white pine $1\frac{1}{8}$ inch thick. All transom sashes to be hung at the top with flat butt hinges and fitted out with hooks and eyes for fastening to carlines. Skylight sash to be hung at the bottom with flat butt hinges and operated with transom sash lifts. Window sash to be fitted out with clamp fastenings for raising and lowering, and of a design as may be selected or approved by the Engineer Officer in charge.

All glass used in the sash and doors to be double strength "American," and of the sizes as shown on the drawings.

The different compartments to be fitted out as hereinafter described.

Kitchen.—The floor to be sheathed with yellow pine, tongued and grooved, seasoned flooring of narrow widths, laid at right angles to the deck.

To have a steel sink of appropriate size and design to be selected or approved by the Engineer Officer in charge, fitted out with hot and cold water connections,

and a 2-inch gas pipe drain leading down and out under main deck of hull; shelving two tiers high to be erected across the after bulkhead. Two wooden tables are also to be furnished, one 30 inches by 96 inches with oak top, the other 30 inches by 60 inches, with an oak top and both with a drawer.

Pantry.—To be fitted out with shelving three tiers high on two sides as shown on the drawings; and a steel sink, similar to that in the kitchen, with hot and cold water connections and a 2-inch gas pipe drain leading down and out under main deck of hull.

Laundry.—To be fitted out with porcelain-lined tubs in three sections, supported on legs and placed as shown on the drawings, and to have hot and cold water connections, with drain pipes from each to a 2-inch gas pipe drain leading over and connecting with drain pipe from pantry. These tubs to be selected or approved by the Engineer Officer in charge.

Store Room.—To be fitted out with shelving three tiers high on three sides as shown on the drawings, the lower shelf being set three feet from cabin deck.

Pastry Room.—To be fitted out with shelving two tiers high on two sides, as shown on the drawings, and furnished with a plain wooden table with poplar top, 30 inches by 54 inches, and a drawer in same.

Plumbing and Pipe Fitting.—There are to be two bath tubs placed as shown on the drawings, one to be 5½ feet long, the other 5 feet long, both to be rolled rim porcelain-lined iron tubs, each fitted out with hot and cold water connections and overflow pipes, and with extra heavy nickel-plated brass fittings, and drained as hereinafter described.

Wash bowls to be of porcelain, marble tops, erected on brackets, furnished with nickel-plated brass trimmings, fitted out with hot and cold water connections and overflow pipes, and drained as hereinafter described.

Water Closets.—To be of porcelain, each fitted out with flush tanks of iron, and all of the necessary appurtenances to make a complete outfitting, and drained as hereinafter described. All of the bath tubs, wash bowls, water closets and fittings to be of a design as may be selected or approved by the Engineer Officer in charge.

Drainage.—Wash bowls and bath tubs to be drained down and out under main deck of hull by 2-inch gas pipes. Water closets to connect with 4-inch gas pipe leading down and out under main deck of hull.

Wash bowls, bath tubs and closets all to be properly trapped and the plumbing throughout to be done in the most workmanlike and sanitary manner, and anything necessary to make the plumbing complete, and not hereinbefore specified is to be furnished by the contractor without additional expense to the Government.

Connections.—All cold water connections are to be made with three tanks of ¼-inch boiler iron, each of 250 gallons capacity. Each tank to be connected with donkey pump in the engine room. Tanks to be located on the port side directly over the cabin clamps, one forward, one over the centre between pantry and laundry, and the other at a point directly over the crew's water closet.

All hot water connections to be made with the boilers and so arranged that water may be obtained from either battery or the auxiliary boiler.

Two stand pipes 2½ inches in diameter, one on each side near midships, extending from main deck through roof and connected with the fire pump to be supplied. These pipes to be provided with brass globe valve hose connections for 2½-inch hose on each deck and on the roof.

Furnishings.—The two forward rooms to be furnished each with a marble top dressing case, with mirror, two chairs, an iron bedstead of neat design with wire mattress for same, and movable locker. Office with two chairs, a rolling top office desk 4½ feet wide of "Tyler" make, or its equal, and a swivel arm chair. Each of the other rooms in the forward cabin to be furnished with one chair, a locker, bureau, with three drawers, a looking glass, a two-story iron bedstead put together with malleable iron fittings, and two wire mattresses for each bedstead.

Dining hall of main cabin to be furnished with two substantial extension tables of cherry, each 10 feet long and 3½ feet wide, with 20 heavy dining chairs to match tables. The after dining hall to have two extension tables of oak, one 9 feet long and 3 feet wide, and the other 14 feet long and 3 feet wide; and 48 heavy oak arm chairs. Sleeping room of after cabin to be furnished with 16 two story iron bedsteads, 6 feet 3 inches by 2 feet 9 inches, put together with malleable iron fittings, with two wire mattresses for each bedstead. The stanchions that support skylight clamps in sleeping rooms to be of 2½-inch galvanized iron gas pipe with flanges at top and bottom.

An oak refrigerator not less than 5 feet wide and 30 inches deep, with a separate compartment for ice on top, to be furnished. The floors of all rooms in the forward cabin and hall to be covered with best quality of linoleum.

All of the above furnishings to be of such design and quality as may be selected or approved by the Engineer Officer in charge.

Stoves.—There is to be furnished a wrought-iron range for the kitchen, one heating stove for forward cabin hall, one for after dining hall, one for sleeping room for crew, and a laundry stove for laundry; all to be set up with the necessary pipe, and of such size and design as may be selected or approved by the Engineer Officer in charge. Roof flanges for stove pipes to be of the design as is used on river steamers, made of galvanized iron No. 22, and at the intersections of pipes with roof; the openings are to be encased with a casing projecting below to a depth of carlines; main hall roof casing to be of neat design, the other plain.

Tinning.—All down spouts and scuppers are to be of No. 22 galvanized iron; to be six each side from skylight roof to cabin roof; to be six each side of cabin roof to cabin deck, 2 inches diameter; six swinging scuppers each side of cabin deck to throw overboard, 3 inches diameter.

Hardware.—Hinges for all doors to be brass hook pin butts; for transom and skylight sash flat brass butts; doors to be fitted out with bronze knobs, brass locks of good quality, and keys; and all of the necessary hooks, eyes and buttons to make complete fastenings; each room in forward cabin to be

furnished with six hat hooks and six coat hooks each. Windows to be raised and lowered with sash clamps and locks ; transom sash lifts and sash clamps to be of a design as may be selected by the Engineer Officer in charge.

Steam Radiators.—Steam radiators of proper design and capacity to be placed, one in each of the forward rooms and two in the forward cabin hall, all properly connected with boilers and fitted out with all of the necessary appurtenances to make complete fitting, and to be of a design as may be selected or approved by the Engineer Officer in charge.

Painting.—All colours to be made of pure white lead and boiled linseed oil, unless otherwise specified. Flat colours do not embrace any linseed oil.

The interior of forward cabin, hall and rooms to be painted one coat of shellac, three coats of flat colours and one coat of zinc gloss. The after cabin, the outside of cabin and skylight, the underside of cabin and skylight roof projection and the guard railing, all to be painted four coats of pure white lead and boiled linseed oil ; all knots to receive a coat of shellac, all nail heads puttied ; the deck outside of cabin to be painted three coats of a light lead colour.

The interior and exterior of lower deck house and stairs, the underside of cabin deck and projections, to receive three coats of paint as may be selected. The name of the dredge and other lettering required to be done as directed.

Workshop and Machine Tools.—A workshop to be fitted up on board and provided with the following machine and other tools, all to be selected or approved by the Engineer Officer in charge.

One 20-inch swing screw cutting slide lathe with compound rest and rod feed. Bed, 14 feet long. Lathe to be provided with full set of change gears, large and small face plates, one 18-inch four-jaw chuck, one 9-inch three-jaw chuck, steady and following rests. The tail stock to have set-over for turning taper.

One 24 or 25-inch swing vertical drill press with back gear and power feed, with quick return motion.

One 15-inch crank shaper with swivel vise.

One bolt and pipe cutter, to cut bolts from $\frac{1}{2}$-inch up to 2 inches diameter, and pipes from $\frac{1}{4}$-inch up to 3 inches ; with a full set of both bolt and pipe dies and of machine taps from $\frac{1}{2}$-inch to 2 inches.

One set of pipe taps from $\frac{1}{4}$-inch up to $2\frac{1}{2}$ inches.

Three pipe cutters. Nos. 1, 2 and 3, to cut pipe from $\frac{1}{4}$-inch to 4 inches diameter. One blacksmith's forge, not less than 24 × 30 inches, with hood and necessary smoke pipes, fixed in place.

One fan blower not less than 3-inch outlet with blast gate and pipes connected to forge.

One portable forge without hood, not less than 20 × 24 inches.

One anvil, weight 200 lbs.

One pipe vise, hinged, to take pipe up to 3 inches diameter.

One full set of pipe tongs, Brown's adjustable tongs up to 3 inches, and chain tongs above 3 inches.

Two machinists' parallel vises ; one 4½-inch jaws and the other 5½-inch jaws.

Hammers—One sledge, 14 lbs. ; one sledge, 10 lbs. ; one blacksmiths' hand hammer, 2 lbs. ; two machinists' hand hammers, 1¼ and 1¾ lbs., one copper or rawhide hammer.

A full set of blacksmiths' tongs and tools.

Twelve machinists' chisels of different sizes.

A full set of adjustable and solid wrenches, for all the machinery on board.

The workshop is to be fitted up with bench, lockers and tool racks.

Workshop Engine.—An engine, 7-inch cylinder, 9 or 10-inch stroke, must be provided for driving the shop tools, and must be furnished with steam from both main and auxiliary boilers. A main line of shafting and all machine countershafts, with all pulleys, hangers and belts, must be supplied and fitted in place in complete running order.

Bidders are to understand that in all cases throughout these specifications where machinery, articles or material of any kind are to be selected or approved by the Engineer Officer in charge, only such as are in his judgment the best to be found in the market, and the most durable and appropriate for the purpose for which they are intended, will be approved. It is not intended to incur expenses in the purchase of flimsy articles of little or no value or endurance, or articles uselessly ornamented and inappropriate to the work to be done.

Material and Workmanship.—The best quality of materials and workmanship will be required in each and every part of the work to be done under these specifications, and no advantage shall be taken of any phraseology, error or omission which would seem to justify other than these. Full information will be given upon any point where doubt may arise.

Character of Material.—All plates and angles to be used in the work under this contract, unless otherwise specified, will be of low steel, 55,000 to 62,000 lbs. ultimate tensile strength per square inch, elastic limit one-half of the ultimate strength, minimum elongation of 26 per cent. in 8 inches, and minimum reduction of area at fracture of 50 per cent. These tests will be made at the mill from the steel of each heat, by inspectors designated by the Engineer Officer in charge, and certified reports thereof transmitted to him. In addition to the above tests, partially cut but not detached test pieces about 2 inches wide and 10 to 12 inches long must be furnished, with at least two sheets out of the lot rolled from each heat ; and tests thereof will be made by bending the metal back upon itself immediately after chilling from a cherry heat by plunging into cold water. When so treated the steel must show no sign of fracture on the outside of the bent portion. In gauging the thickness, measurements will be made at each corner and at different points throughout the area. A variation of more than 2½ per cent. above or below the specified thickness will cause plates to be rejected. Facilities must be furnished the inspector by the manufacturers for making these tests, the cost of which will be borne by the contractor. The rivets to be of soft steel, not more than 61,000 lbs. nor less than 55,000 lbs. ultimate tenacity, with

an elastic limit of not less than 34,000 lbs., and a ductility of not less than 26 per cent. in ten diameters, and must be capable of bending double flat without a sign of fracture on the convex side of the bend.

Inspection.—Inspectors will be appointed by the Engineer Officer in charge to inspect, at the shops and on the dredge during the process of construction, the material furnished and the work done, and see that the same conforms strictly to specifications and requirements of the contract. The contractor must at all times give the inspectors free access to the material and work, and afford every facility for their inspections. The decision of the Engineer Officer in charge upon all questions arising under these specifications shall be final, and he shall have the right to require the immediate removal, at any time, of any employee of the contractor found incompetent or otherwise objectionable.

Inspector's Examination.—Before beginning the tests, the inspectors appointed by the United States Engineer Officer in charge shall go over the dredge and plant carefully, to determine whether everything called for in the contract has been provided and is in proper working condition. No test shall begin until everything lacking shall have been supplied.

Imperfect Work.—Any unfaithful or imperfect work, or defective or improper material, that may be discovered before the final acceptance of the dredge, shall be corrected immediately. The inspection of the work and material during the process of construction shall not relieve the contractor of any of his obligations to perform good work and furnish good material as herein specified.

Contractor's Test.—Prior to the commencement of the general efficiency test, the contractor shall satisfy himself of the proper operation of the dredge and of the sufficiency of each and every part, by raising steam to the allowed limit and working each and every part as it is intended when the dredge is in full operation.

Efficiency Tests.—Before the dredge is accepted a general efficiency test will be made, extending over a period of ten days of 24 hours each, and the result of which will be determined by the percentage of lost time due to defects of the machinery when compared with the actual time available for dredging. The test will be made under the ordinary conditions of actual every-day work, and for this purpose the dredge shall be run to its full capacity and shall deliver its material through the full length of 500 feet of discharge pipe. The movements of the dredge and the selection of places where dredge is to be placed shall be entirely under control of the Engineer Officer in charge or his appointed agents. When the contractor is prepared to make the test, he shall notify the United States Engineer Officer in charge to that effect, and shall then hand over the dredge to the United States agents appointed to take charge. The tests will be made by the officers and crew selected by the Engineer Officer in charge, due consideration being given to any recommendations of the contractor as to competent employees, and at the expense of the United States Government. The contractor or his representatives may be present at all tests, and a copy of

all records of tests shall be furnished him on application. An accurate log will be kept of all the operations of the dredge, recording the times at which the pump is stopped or started and a statement of the cause of each stoppage, from whatever source it may arise. All Sundays and holidays, time taken in towing and mooring, time lost in moving out of position for passing vessels and back again, shall be deducted from the ten days and the balance considered as "available dredging time," which shall form the basis for determining the percentage of "lost time," due to stoppage of any part of the machinery or plant which is the subject of the contract. The "lost time," taken during the whole period of ten days of 24 hours each, shall not exceed twelve per cent. of the "available dredging time." In case this limit is exceeded, the dredge will be returned to the contractor and the cost of the efficiency tests previously made will be deducted from any sums due or to become due the contractor. When the contractor notifies the Engineer Officer in charge that he has remedied the defects, and is ready to commence new tests, the dredge will be returned to the Government agent and a second series of efficiency tests proceeded with in the same manner. It is to be understood that no repairs shall be made on Sundays or at times when the dredge is considered to be not at work, excepting such things as are ordinarily done at that time to keep the machinery in proper working order, as washing out boilers, packing stuffing boxes, tightening joints, stripping brasses, etc. All the cost of repairs during the efficiency tests shall be borne by the contractor.

But two series of efficiency tests may be made. Should the dredge finally fail to meet the contract requirements, the right is reserved to either reject it or to accept it at such reduction in price as the Engineer Officer in charge, with the approval of the Chief of Engineers, U. S. Army, may find necessary in order to reimburse the United States for all damages sustained by reason of said failure, including the cost of all tests and the cost of remodelling the dredge so that it shall meet the contract requirements.

For each and every day's delay in the delivery of the dredge beyond the time specified for this in the contract, there shall be deducted from the contract price of the dredge, as liquidated damages, the sum of one hundred and fifty dollars ; provided that this delay be not caused by freshets, or ice or other force or violence of the elements, which ordinary foresight on the part of the contractor could not provide against.

Explanations and Corrections.—Any doubt as to the meaning of these specifications or any drawings or explanations that may be furnished the contractor, or any obscurity in the wording of them, will be explained by the Engineer Officer in charge, who shall have the right to correct any errors or omissions in them, when such correction is necessary for the proper fulfilment of their intention.

Extra Work.—No claim for extra work or material, or for delays of any kind, will be considered or paid for unless an agreement therefor shall be made in writing and approved by the Chief of Engineers, U. S. Army. The contract price is to be full compensation for furnishing all materials, labour and

appliances necessary for doing all the work and furnishing the dredge herein specified.

Port of Delivery.—The dredge to be delivered at Cairo, Ill., or St. Louis, Mo., at the option of the contractor.

Time of Delivery.—The dredge and all its appliances and appurtenances must be completed in all and every part, and handed over to the Engineer Officer in charge for test, within six months from the date of notification of approval of contract. If there be no delay caused by defective or imperfect machinery developed during efficiency test rendering necessary a second series, the date of the commencement of this test will be considered as that of the delivery of the dredge. Should there be delays from the causes above mentioned, rendering necessary a second series of efficiency tests, the date of delivery will be taken as that on which the dredge is turned over to the Engineer Officer in charge for the new tests.

Interpretation of Terms.—In case of any disagreement concerning the interpretation of the provisions of these specifications, the decision of the United States Engineer Officer in charge shall be binding.

Patents.—The contractor shall guarantee the Government against any claims or awards for damage on account of infringement of patented devices, which he shall furnish to the dredge, at his own option.

Omissions, etc.—All necessary adjuncts, parts or attachments properly forming a part of the dredge, and requisite for the proper and efficient working of the machinery, shall be understood to be included in these specifications, whether mentioned herein or not, and shall be supplied by the contractor as forming part of the contract. And it shall be further understood that, notwithstanding the general drawings are furnished by the United States, the contractor shall be responsible for the strength and efficiency of all details, except in cases where special materials, dimensions and arrangements are specified, and full detailed drawings of construction are provided.

ST. LOUIS, Mo., Feb. 6th, 1897.

THOS. H. HANDBURY,
Major, Corps of Engineers, U. S. A.

APPENDIX E.

SPECIFICATION

FOR CONSTRUCTING AND DELIVERING

THREE STEEL-HULLED STEAM TENDERS.

GENERAL DESCRIPTION.

Hull.—Length from bearding line of stem to main transom shall be one hundred feet; length from bearding line of stem to splash bulkhead shall be one hundred and two feet; width on floor in straight body, twenty-two and one-half feet; width on deck over frames straight body, twenty-four feet; width on deck over nosings straight body, about twenty-five feet; depth of hold at sides at lowest point over frames, four and one-fourth feet; crown of deck, four inches; sheer forward, one and three-fourths feet; sheer aft at main transom, six inches; radius of knuckle, six inches; the plating for knuckle and keel shall be five-sixteenths inch thick; the plating for sides and bottom shall be one-fourth inch thick; the plating for deck and bulkheads shall be three-sixteenths inch thick; the frames shall be spaced eighteen inches, centres, sides and floors of angles three and one-half inches by two and one-half inches by five-sixteenths inch, deck beams of channels four inches deep by five and one-fourth pounds per foot. The hull shall have hog and other chains and all other appurtenances required as shall hereinafter be specified more particularly.

Boiler.—There shall be one boiler of the Mississippi River type, twenty-four feet long, forty-two inches inside diameter, with two flues eleven inches and two flues nine and one-half inches. Shell and flues thirty-one-hundredths inch thick of best Marine Steel, sixty-five thousand pounds tensile strength per square inch, with all appurtenances required as hereinafter specified.

Engines and Machinery.—There shall be two main engines each with cylinder twelve inches diameter by five feet stroke with balance poppet valves, expansion joints and adjustable inside connected cut-off, "California" or other approved type, engines for two steam capstans and one feed pump, all suitable to work satisfactorily with pressure of steam not exceeding two hundred pounds per square inch above atmosphere. The wheel shall be thirteen feet diameter over buckets by seventeen feet in length and twenty-eight inches width of buckets.

Deck House and Upper Works.—The deck house shall extend from rear of forecastle to splash bulkhead and will be about eighty-nine feet long, divided into boiler room, coal room deck, room and engine room. It shall be nine feet

high and twenty-four feet wide. The pilot house shall be located over the forward end of the deck house ten feet fore and aft, and eleven feet wide by seven feet high in the clear above the deck house roof. This general description gives in outline the work to be done in building these tenders of the best materials and in the most workmanlike manner, and as hereinafter more particularly described.

SPECIFICATIONS IN DETAIL.

Framing.—The hull shall be built upon transverse and longitudinal systems of framing. The former shall comprise the transverse frames and bulkheads, while the latter shall comprise the keel, keelsons, stringers, longitudinal bulkhead, stem and stern posts, and in both systems each item named includes all the appurtenances required or necessary to complete it.

Transverse Framing.—A transverse frame shall comprise a floor, two sides and a deck beam with the outriggers, gussets, clips, and all other connections specified or required to complete it.

There shall be sixty-seven transverse frames, numbered 1 to 67 inclusive for reference, No. 1 being twelve inches and No. 6 seven feet from the bearding line of stem, and No. 67 eighteen inches forward of the main transom. The sides and floors of each frame shall be of three and one-half by two and one-half by five-sixteenths inch angle bars, long leg set vertical and composed of two lengths of bar each extending from centre line of keel plate to top of side. The sides of frames No. 1 to No. 6, inclusive, shall abut on the stem and be securely connected thereto and to each other and shall be spaced as shown. All frames aft of No. 6 shall be spaced eighteen inches between centres, and shall have their floors spliced over the keel plate by butt straps of three and one-half by two and one-half by five-sixteenths inch angle bar, long enough to extend beyond the first keelson on each side, reversed with the long leg vertical and well rivetted.

The deck beams shall be of four inch channels, five and one-fourth pounds per foot, one to each frame to the sides of which it shall be connected by gusset plate securely rivetted, and supported by stanchions of two inches by two inches by three-sixteenths inch angles, six under each beam placed under the deck stringers rivetted at top and bottom.

Transoms.—There shall be a main transom constructed of a web of one-half inch steel plate shaped to fit the crown of the deck and rake, and shall have angle bars three inches by three inches by five-sixteenths inch rivetted to top and bottom edges on forward side to receive plating. There shall also be a false transom of seven inch channel bar connected between cylinder timbers and connected to main transom by one-fourth inch gusset plates and three inch angle clips, spaced about three feet apart so as to form openings for rudder posts.

Stem.—The stem shall be built of a vertical steel plate one-half inch thick and twenty inches wide at the top, with a cheek piece of steel on each side eight inches wide and three-fourths inch thick, making the face of stem two inches broad. Below shall be a flange apron ten inches wide upon the floor, varying in thickness from one-half to three and one half inches. It must scarf up into and terminate the above pieces of the stem, itself terminating at frame No. 7. The stem plate shall be connected to the deck plating and to all frames intersecting it by means of angle clips and gusset plates. All as shown on the drawings. A sheet of copper three and one-half inches wide and one-eighth inch thick shall be secured on each side of the stem under the hull plating.

Keelsons.—The main keelson shall be of double angles two and one-half inches by two and one-half inches by one-fourth inch, back to back, inclosing the plating of main keelson bulkhead, of which they form a part. The angles shall be in long lengths, break joints, and be connected by butt straps of the same.

Knuckle keelsons, one on each side, shall be of angles four inches by six inches by three-eighths inch long leg vertical, in long lengths and joints secured by butt straps of the same sized angles as those joined, and in lengths to cover at least three frames, to which they shall be connected by angle clips of the same size and thickness.

Other keelsons or floor strakes shall be three each side of main keelson dividing the space between main and knuckle keelsons into four equal or nearly equal parts as shown. These keelsons shall be of angles three and one-half inches by two and one-half inches by one-fourth inch in long lengths with joints secured by butt straps of the same. All keelsons shall be securely rivetted to frames by angle clips.

Boiler Beams.—There shall be two sets of boiler beams each composed of three four inch channel bars, weighing five and one-fourth pounds per foot, spaced and located as shown.

Stringers.—There shall be a deck stringer over each keelson and floor strake and two side stringers on each side, all of angle bars three and one-half inches by two and one-half inches by one-fourth inch, except the central one. The central deck stringer shall be formed same as the main keelson of the angles doubled, two and one-half by two and one-half by one quarter inch, placed back to back with the bulkhead web between. All stringers shall be joined by butt straps of angles of the same size and thickness, long enough to cover three frames, and shall be securely rivetted to frames by means of angle clips.

Breast Hook.—The breast hook shall be of angle bars four inches by six inches by three-eighths inch and extend ten feet on each side of stem. The short leg shall set vertical and the breast hook shall be securely rivetted to each frame by means of angle clips, and shall be stiffened by two stretchers each of one-half inch plate, and with angles three inches by five inches by one-fourth

inch. The forward stretcher plate shall be twelve inches wide to receive heels of bitts, and the aft stretcher plate shall be six inches wide.

Bulkheads.— There shall be four cross and one main keelson bulkhead, all of three-sixteenths inch plate stiffened on opposite sides by diagonal braces of angle bars two and one-half inches by two and one-half inches by one-fourth inch. The cross bulkheads shall be made thoroughly water-tight, using intercostal plates wherever required to secure complete connection from plating of deck to that of bottom. The main keelson bulkhead will not be required to be water-tight but shall be well fitted, metal to metal, and intercostalled under the deck plating and over bottom plating, with limber holes in the bottom intercostals.

The forward cross bulkhead shall be located upon cross frame No. 13. No. 2 shall be on frame No. 28 ; No. 3 on frame No. 44 ; No. 4 on frame No. 60. They shall extend from side to side and from bottom plating to deck plating and shall be continuous except that they shall be worked intercostal with all floor strakes, side and deck stringers.

The longitudinal bulkhead shall extend centrally through the boat over main keelson from a point four and one-half feet forward of the forward cross bulkhead to the main transom fitted metal to metal throughout with intercostals its entire length. It shall be worked intercostal with the cross bulkheads and a man-hole shall be made in it above keelson in each compartment between cross bulkheads. The longitudinal bulkhead shall be carried out to the stem in the shape of an I beam twelve inches high, using the same sized angles of longitudinal bulkhead to form the flanges.

All bulkheads shall be stiffened throughout by diagonal braces on both sides of plating formed of two and one-half by two and one-half by one-fourth inch angles.

Plating.—The plating for the keel and knuckle shall be five-sixteenths inches thick. The plating of the sides, bottom and all gussets shall be one-fourth inch, and for deck and bulkheads three-sixteenths inch thick.

The thickness of all butt straps for deck plating and bulkhead plating shall be one-sixteenth inch greater than that of the thicker of the plates connected.

Outside plating of hull shall not be less than ten frame spaces in length. Longitudinal seams may be lapped, transverse seams must be butted. The butts of adjoining strakes shall have a shift of not less than two frame spaces, and those of alternate strakes a shift of not less than one frame space.

The butts of all outside plating shall be planed or chipped fair and fitted close, metal to metal, and all shearing shall be done from the faying surface of plates. The butts of bottom plates shall be treble rivetted and have single butt straps ten and five-eighths inches wide and one-eighth inch thicker than the plates which they connect. The butts of side plates shall be double rivetted and have single butt straps seven and one-fourth inches wide, and one-eighth

inch thicker than the plates which they connect. All butt straps shall be in one piece and entirely cover the seams over which they are fitted. The fibre of double and treble rivetted butt straps must be in the same direction as the plates to which they are secured. All longitudinal seams of outside plating shall be single rivetted lap two inches wide. Solid liners in one length shall be fitted at every frame, between frames and outside strakes of outside plating. Liners shall be the width of the flange of the frame to which they are fitted, and shall be carefully fitted so as to fill the entire space between the edges of the inside strakes. All butt straps shall be on inside of hull, and all outside plating rivets shall be countersunk on outside. All seams intended to be water-tight must be thoroughly caulked.

The deck plating shall be three-sixteenths inch thick. All seams shall be double rivetted, butt jointed, with single straps on under side seven and one-fourth inches wide and one-sixteenth inch thicker than the plates they connect, with rivets countersunk into deck plate. The deck shall be further stiffened or supported from below at points carrying the heels of stanchions, heels of braces, or machinery; also at the points of attachments of capstans, timber-heads, chocks, kevels, snatch-blocks, and guys.

The hull shall be divided into five water-tight compartments by athwart-ship bulkheads, as shown on drawings. Bulkheads shall be three-sixteenths inch thick, on each side, stiffened with two and one-half inches by two and one-half inches by one-fourth inch angle bars, and butt jointed with rivetted seams. The intercostals for all bulkheads shall be of pressed plates one-fourth inch thick. All holes cut in bulkheads shall be efficiently compensated where necessary, and made thoroughly water-tight.

Rivetting.—The rivets shall be of soft steel and five-eighths inch diameter throughout the hull, except where otherwise specified or noted on drawings, or where the nature of the work requires a different size. The rivets in seams or laps of outside plating shall be spaced longitudinally not more than two and one-half inches, centre to centre. And rivets in seams or laps of all internal water-tight work shall be spaced not more than two and three-fourths inches centres. All double rivetting, including butts, shall be chain fashion, except where otherwise noted on drawings, the distance from centre to centre between the rows to be one and five-eighth inches. No rivet shall be nearer the seam, butt, or edge of plate or angle bar, than its diameter. Spacing of rivets in beam knees shall be from two and three-fourths inches to three and one-eighth inches centres, but no beam knee shall be secured to its frame or beam with less than four rivets. Rivets for securing outside plating to floors and frames, stiffening angle bars to bulkheads, and all work where angle bars do not require to be caulked, shall be spaced not more than five inches centres. Rivet holes shall be regularly spaced and punched from faying surfaces and shall be opposite each other in adjoining surfaces. Heavy drifting shall not be resorted to. Holes not punched fair shall be drilled or reamed fair and a size

of rivet to fill the hole shall be used. Countersinks shall be not less in depth than three-fourths the thickness of plate or angle bar countersunk. Rivets to completely fill their respective holes, and the heads shall be laid up in outside plating and all other water-tight work; the points of rivets when finished to completely fill the countersinks and be slightly convex or flush with their respective plates or angle bars.

Chocks.—Four sets of wrought-iron double sheaved side chocks and a centre chock with four sheaves, all of five-eighths inch and seven inches iron, and furnished with turned cast-iron sheaves, six inches diameter and three and one-half inches thick, shall be provided and placed as shown on drawings, and rivetted to the top plate and fastened with button head sheave bolts, from top of cap of chocks to top plate of head-block, one and one-half inches diameter, and through block one and one-fourth inches diameter, with nut and plate attachments. The corners of all chock plates to be neatly rounded wherever they may come in contact with the lines.

Bitts.—The bitts shall be of black locust eight inches by eight inches, placed as shown on drawings. The timber heads shall pass through the deck and heel in a shoe of three inches by three inches by five-sixteenths inch angle bar or forward breast hook stretcher, as shown and required. The deck around the opening for the bitts shall be reinforced with three inch by three inch by one-fourth angles.

Stack Knees.—There shall be four sets of stack knees placed as shown on drawings, and each made of three-sixteenths inch steel plate, with edges capped by angle bars two and one-half inches by two and one-half inches by one-fourth inch. Two angles three inches by three inches by one-fourth inch shall be rivetted to the face of each set of knees to receive an oak backing piece six inches by eight inches bolted through the face plate, and shall have swinging fenders of oak five inches by twelve inches hung as required. Each set of stack knees shall have four feet face on deck line, and be three feet high.

Kevels.—There shall be fourteen kevels of steel castings, of which twelve shall be seven inches by seven inches by four feet and two seven inches by seven inches by five feet. All should be of approved pattern and placed as shown on drawings. The four side kevels at the after capstan shall be provided with sheaves similar to those of the chocks as shown.

Head Block.—There shall be a head block in the form of a box beam made of two ten inch channel bars, twenty pounds per foot, with channels reversed and with a three-eights inch by eight and one-half inches steel plate on top and bottom rivetted through flanges of channels, extending across the head and about seven feet aft the centre of stack knees on both sides, then curving down and membering with a seven inch channel bar nine and three-fourths pounds per foot, and continuing back to its intersection with the hull. The head block shall be securely fastened to the stem with three-fourths inch bolts and angle clips four inches by three inches by five-sixteenths inch.

The front filling of channel bar shall be of oak two and one-half inches by ten inches bolted through at top and bottom with one-half inch bolts to receive the nosing. The after side of the head block shall have a three inch by three inch by one-fourth inch angle extending around from side to side to receive the deck plating.

Outriggers.—The outriggers shall be made of one-half inch steel plate for a web, with three inches by three inches by one-fourth inch angles at each side at top and bottom edges and shall be connected to hull plating by gusset plates, and to head block by angle clips, as required. The underside of forecastle guards shall be sheathed with one inch yellow pine boards well secured to oak pieces two inches thick, bolted to outriggers with one-half inch screw bolts.

Fantails.—There shall be a fantail on each side of the wheel aft of main transom. Each shall be formed of two seven inch channels, nine and three-fourths pounds per foot, rivetted back to back connecting with the cylinder timbers aft of wheel, the outside piece extending forward six feet on the side of the hull, and rivetted to the same. The inside piece shall abut against the main transom, and be connected to the same by angle clips. The connection with the cylinder beams shall be secured by one-half inch steel plates on top and bottom sides. The running piece shall also be of seven inch channel, nine and three-fourths pounds per foot, with back of channel to pitman port connected at both ends by angle clips, and the space between running and outside pieces shall be filled with three inches by two inches by one-fourth inch angles, twenty-four inches pitch well connected to channels to receive the deck plating.

Cylinder Beams.—The cylinder beams shall be of fifteen inch I beams, fifty pounds per foot, shaped at the bottom to conform to the deck sheet. The long cylinder beams shall be connected to main transom by means of six inch by six inch by one-half inch angle clips.

The cylinder beams shall be connected with a pan of three-sixteenths inch sheet steel, extending from forward end of cylinders to after ends of slides, turned up three inches on the side edges and rivetted to web of the beams.

Key plates shall be bolted through beams and backed up by a flange piece rivetted to top of beams and at the intersection of lash chain braces and pillow block, the top and bottom shall be reinforced with a plate of steel one inch by seven inches long enough to receive key plates, and rivetted through the flanges.

The beams shall rest on and fasten through a bed plate of five-sixteenths inch sheet steel, extending from their forward end to main transom and three inches outside of their flange projections, and have flanges turned up at side edges two inches. The beams shall be rivetted through flanges, bed and deck plating, the whole fitted down tight and the bed plate shall have drain pipes at forward end, leading under deck and overboard.

A truss of three inches by three inches by one-fourth inch angles shall be placed in the hull upon the keelson under each long cylinder beam from transom to forward end of cylinder beams, and the machinery bolts shall take hold of the lower chord of this truss with three-quarter inch by six inch by six inch washer plates. In fastening down the beams and engines the bolts shall be binding of iron and iron, or iron bound bolts, one and one-fourth inches diameter, connected below deck with swivel attachments and placed as required.

All key and pillow block bolts near shaft shall extend through the beams and have heavy cast-iron washers between nuts of bolts and beams.

Levelling plates of steel shall be rivetted to top of short cylinder beams, under the outer bed plates of cylinders and slides, and long enough to receive key plates.

Stern Posts.—There shall be two side stern posts and one false post at the middle located as shown, to receive rudder irons. Each shall be formed of ten inch channel bars, fifteen pounds per foot, and extend five feet above deck and the side stern posts fifteen inches below transom, to which they shall be connected by three inch by three inch by one-fourth inch angle clips, and to rake plating by gusset plates of one-fourth inch steel to form a small skeg for the attachment of the lower rudder irons.

Side plates of posts shall be one-fourth inch steel, ten inches wide, rivetted to flanges of channels and to three inches by three inches by one-fourth inch angles on face of posts, and the plates shall be connected by lateral bracing of one-fourth inch by two inches steel, and the intersection at the deck shall be stiffened and gusset plates of one-fourth inch steel, extending twenty-four inches in over deck and twenty-four inches upon face, and the top shall be stiffened by three inch by three inch by one-fourth inch angle braces. Two chains of five-eighths inch round iron shall be connected to top by bands of one-half inch by three inch iron with two lug attachments, and to deck plating by plates of three-fourths inch by six inches with eye attachments, and all with swivel connections. Braces and chains shall be set fore and aft at an angle of 45° with the deck. There shall be four athwartship chains, two connecting sides of centre post and one on each side post, all of the same sized iron and connected in the same manner as the forward chains.

Rudders.—There shall be two balance rudders, with stocks of lap welded steel tubing, nine inches outside diameter, metal one-half inch thick, and the blades of white oak three inches thick, the stock of each rudder extending seven and one-half feet above deck, well secured to posts each with three sets of rudder irons and pins one and one-eighth inches diameter, and each stock shall be encircled by one iron plate three-fourths inch by ten inches bolted to it to receive the tiller arm. The rudder stocks shall be slotted to receive the blades and the corners of the slots shall be rounded.

Two iron plates, three-fourths inch by nine inches shall encircle and be rivetted to stocks, and be bolted on each side of each blade below lower rudder

irons, and one plate of three-fourths inch by seven inches shall encircle and be rivetted to the stock and bolted to the blades above lower rudder iron. The lower face of blades shall have a four-inch by four-inch by one-fourth inch angle bar, each side bolted through blade, and the top and bottom edges of blades shall be protected by a band of iron one-fourth inch by three inches well fastened, and each rudder shall have wrought-iron bumpers constructed as required.

Tillers.—The centre tiller shall be thirteen feet and the side tillers each eight and one-half feet total lengths, all of steel, the side tillers connected to stocks six inches from their tops, and the centre tiller shall be hinged to a false stern post. Each tiller shall be made of four three-inch by three inch by one-fourth inch angles, with one-fourth inch steel plates for webs, well rivetted and bolted to the iron plate on the head of stock, and stiffened on the top and bottom sides with lateral braces of one-fourth inch by two inches iron, and one-fourth inch plates on top and bottom sides at intersections of rudder stocks tiller and coupling connections and end of tiller, and with tiller couplings of five-inch I beams nine and three-fourths pounds per foot, constructed and connected in a manner approved by the Engineer Officer in charge. The forward end of centre tiller shall be supported by a sheave six inches diameter running upon a circular track of three-fourths inch by two and one-half inches iron hung from the carlines, and the after end pivoted on a pin two and one-half inches diameter, forged to a rudder iron at the top of centre stern post.

There shall be a box around each rudder stock extending four feet above deck, twenty-three inches by thirty-six inches built of one-fourth inch steel plates and two-inch by two-inch by one-fourth inch angles bolted to bulkhead which will form one side of the box. The boxes shall be made water-tight.

Chain Braces.—The chain braces shall be of white pine, main side, wheel, hog and relief chains six inches by six inches and wing and back lash chains five inches by five inches. All except the wheel chain and back lash braces shall heel in shoes made of three inches by three inches by five-sixteenths inch angle iron, located as shown rivetted to deck plating, which shall be reinforced by rivetting one-half inch steel plates on under side of it. The heads of all braces shall be protected by cast-iron chairs shouldered down on them. Wheel chain braces shall heel in cast-iron sockets resting upon the cylinder beams vertically over the main transom, and the back lash braces shall heel on cast-iron sockets fastened to the cylinder beams. The deck shall be reinforced under the heels of all chain braces by a filling of cedar between the deck beams and by a plate under beams, and all supported by bracing as shown.

Chains.—There shall be one main hog chain of one and one-fourth inches round iron taking hold forward on main keelson bulkhead under after end of boiler, and aft at frame No. 65, with two side branch chains taking hold on the same frame under the long cylinder beams. Each of these chains shall be secured to the longitudinal bulkhead by means of two steel straps three and one-half inches by three-eighths inch extending diagonally across the bulkhead

and firmly rivetted to the web and flange angles of the same. The ends of the chains shall fasten to these straps by a one and one-half inch pin just above deck.

There shall be two side chains of one and one-fourth inch round iron, each taking hold forward at cross bulkhead No. 1 and aft at the main transom under the long cylinder beams. There shall be one relief chain each side, of one and one-fourth inch round iron taking hold under the heels of side chain braces.

There shall be one wheel chain each side of one and one-fourth inch round iron taking hold at a point under the engine cylinders, passing over the head of wheel chain brace connecting at that point with back lash brace chains of same size iron, leading aft and connecting to cylinder beams forward and aft of wheel shaft.

There shall be three sets of wing chains of one inch round iron each taking hold at the outside keelson strake and heeling on the centre bulkhead and located as shown. There shall be a chain each side of one and one-fourth inch diameter, leading forward from head of wheel chain braces and connecting with main side chains.

All chains shall be of the best charcoal iron, with swivel connections, as required and shown on drawings.

Nosing.—The nosing shall be of oak five inches thick by seven inches wide, and on the sides shall be incased between the gunwale angle and a three-inch by three inch by one-fourth inch angle, rivetted to side along the straight body of the hull, extending from after end of fantails to intersection with head block channel where it shall be two and one-half inches thick. It shall be bolted through plating and channels with three-fourths inch screw bolts with heads well let down into nosing and the openings plugged. A layer of hair felt one-fourth inch thick laid in red lead shall be placed behind the nosing upon its full length. The nosing shall be protected eight feet each way from each corner of the forecastle guard by a plate of steel one-fourth inch by six inches.

Gunwale angles.—There shall be two gunwale angles three inches by three inches by three-eighths inch rivetted to the upper edge of the plating, one on each side from the stem to frame No. 64. The deck plating shall be rivetted to the gunwale angle and deck beams.

Hatches.—The hull shall have two hatches to each water-tight compartment and all others required, each with suitable coamings, gratings, covers, rings and ladders; and each water-tight compartment shall be furnished with three-inch syphon, for which the discharge pipes shall be attached to outside plating by flanges and bolts; each furnished with a steam valve placed so as to be easily accessible from deck.

MACHINERY AND BOILER.

Engines.—There shall be two main engines of the conventional poppet balanced valve type with expansion joints in side pipes, with "California" or other

inside connected adjustable cut-off and shifting gear placed and connected with cross shafts either on or under deck as required; all of a pattern approved by the Engineer Officer in charge. The cylinder for each main engine shall be twelve inches diameter by five feet stroke, steam valves four inches, exhaust valves four and one-half inches, piston rod three and one-half inches diameters respectively. The packing for piston rods and cylinders shall be gun metal filled with babbitt, diagonal in form, and that for cylinders set with elliptical springs. Main and all other engines shall be complete in every particular and shall be built to work satisfactorily with any desired steam pressure not exceeding two hundred pounds per square inch above atmosphere. All cast-iron used in the construction of machinery shall be of the best quality, clean and close grained and shall have a tensile strength of not less than twenty thousand pounds per square inch, and all castings shall be free from blow holes, shrink cavities, contraction cracks, slag, kish, shot, dirt, cinders, blisters, cold shuts and all other defects.

Pitmans.—The pitmans shall be twenty feet long ; the brasses at each end bored three and one-half inches diameter for bearings four and one-half inches long ; the body of pitman shall be of clear white pine in two pieces, free of heart ; the depth at middle shall be twelve inches deep inside of straps and eight inches thick. Pitman straps shall be of best charcoal iron, three and one-half inches wide and three-fourths inch thick, at centre of pitman increasing in thickness toward the ends until the straps meet to form jaws to receive brasses. The straps shall be bolted with screw bolts one-inch diameter about twelve inches between centres. The gibs shall be of best forged steel. Tee-heads shall be of steel castings with adjustable jaws and wrist pins on cranks and tee-heads shall be three and one-half inches diameter and shall be of best forged steel and all annealed. The slides shall be of cast-iron and rest on cast-iron bed plates.

Boiler.—There shall be one boiler forty-two inches in diameter, twenty-four feet long with four flues of which the two upper shall be of eleven inches and the two lower shall be nine and one-half inches outside diameter, with steam drum, mud drums, man-holes, hand holes, valves, pipes and connections. All connections with boilers, drums or pipes shall be made by flanges with compensation for all openings as required. The forward mud drum shall be nineteen inches diameter, and the after mud drum sixteen inches diameter, each four feet long. The steam drum shall be twenty-five inches diameter by six feet long and connected to boiler by a leg twelve inches diameter and ten inches long of seven-sixteenths inch steel plate with a man-hole in one end of drum elliptical in form with diameters ten inches and fifteen inches respectively, with a wrought-iron ring three-fourths inch by two and one-half inches rivetted around man-hole, and rivet heads countersunk. The boiler shall be provided with a three-inch pop safety valve.

There shall be a man-hole in the boiler head above back connection, of same size and form as that in steam drum, and a hand hole of similar form, with

diameters four inches and seven inches respectively, in the head of the boiler under the breech connections; there shall also be hand holes in each end of both mud drums, each with diameters six and one-half inches by nine inches, and a two-inch check valve of approved pattern, and a "Lunkenheimer" gate valve connected to after mud drum, each with valve and seat of hard brass. All man- and hand holes shall have suitable arches and covers.

Each mud drum shall have one mud valve connected at end of drum on the bottom, and blow off pipes one and one-half inches diameter leading over-board under deck with two valves for each pipe, one a glove valve and the other a mud valve with hollow stems one and one-half inches diameter.

The boiler front shall be of cast-iron thirty-eight inches high under shell and provided with fire liners nine inches deep, with ash pit, fire and poker hole doors, and bearers for slashing bars. Grate bars shall be four feet eight inches long over all with four feet of open bar. Breadth of grate between furnace walls, fifty-two inches.

A hole four and one-half inches diameter shall be cut in forward end of steam drum for steam pipe connections. The boiler head shall be eleven-sixteenths inch flange steel; shells, flues, steam and mud drums thirty one-hundredths inch thick, of best Marine steel, sixty-five thousand pounds tensile strength. The legs of mud drums shall be seven-sixteenths inch thick and eight inches diameter; rivets five-eighths inch diameter spaced not more than two inches between centres. The longitudinal seams shall be double rivetted and no longitudinal seam shall be in fire space. Width of shell sheets shall be fifty inches. Height of grate above ash pan shall be twenty inches. Opening to back connection shall be eight inches square closed with suitable door.

The boiler shall rest upon two boiler stands made up of plates and angles, seventy-eight inches long and located as shown.

Steam drum shall be double rivetted and mud drums single rivetted, located as shown on drawing. Casing of fire bed, breeching, flue caps, chimney casing, and smoke stacks shall be of No. 12, A. W. G. sheet steel.

Smoke stacks shall be twenty-four inches diameter, twenty-five feet high above grade. All boiler work must be done in accordance with best modern practice including stays, and in every particular to meet the requirements of law for a safe working pressure of one hundred and eighty-six pounds per square inch above atmosphere and shall withstand, without injury, a hydraulic pressure of two hundred and seventy-nine pounds per square inch.

The ash pan and chute shall be of one-fourth inch sheet steel of the dimension shown on drawing and covered with the best split fire-brick one and one-fourth inches thick, laid in best Portland Cement.

Bridge wall, fire bed, back and side walls, shall be built of the best fire brick, laid in fire clay, and the whole inclosed in a frame of No. 12, A. W. G. sheet steel, the seams rivetted and stayed with angle bars, fastened to boiler, and the fire bed supported by cross bars and stands as required. The space between the boiler and

back and side walls and top of bridge wall shall be covered with the best tiling two and one-half inches thick. The furnace shall be constructed of the best fire brick laid in fire clay. Its depth under shell of boiler shall be sixteen inches on top of grate bars, arranged to raise or lower a variation of four inches.

Feed pumps and heater.—There shall be one Worthington duplex, outside packed boiler feed pump with a capacity of twelve gallons per minute at not more than thirty strokes and of a pattern approved by the Engineer Officer in charge.

There shall be a heater furnished with coils necessary to make its capacity sufficient to supply feed water at a temperature of not less than one hundred and eighty-five degrees Fahrenheit, of pattern approved by the Engineer Officer in charge.

Deck pump.—There shall be one deck pump known as a horizontal double acting "Challenge" force pump No. 12, with cylinders five inches diameter, and connected with boiler feed pipe through a one and one-half inch gate valve.

Steam pipe and fittings.—The main steam pipe shall be four and one-half inches diameter, connected at steam drum with a four and one-half inch high pressure gate valve of "Lunkenheimer" pattern, two branch pipes each three and one-half inches diameter, and one throttle valve on throttle carriage in customary place. The throttle valve shall be reinforced for steam connections for feed pump and deck pump and for any other steam connection that may be required. Exhaust pipes shall be six inches diameter from engines to heater; thence to chimney through an eight inch pipe with a butterfly valve eight inches diameter, to after end of boiler and from that point six inches diameter, terminating in chimney with a three-inch nozzle of three-sixteenths flange steel. There shall be an exhaust pipe eight inches diameter, from heater to roof, and two five-inch diameter from heater to wheel all through butterfly valves. All exhaust pipes shall be of lap welded steel boiler tubing of standard thickness and put up with wrought-iron flange couplings.

The supply shall be carried through the eight inch exhaust pipe by a two-inch pipe from heater to after end of boiler where it will branch down and connect with mud drum.

All fittings, steam, exhaust and drains for feed water, blow out, etc., shall be as required, and in the main, flange couplings, or where those are not suitable, brass couplings will be required. An automatic drop sight oiler will be required for the feed, and ordinary oilers for all other places where required; and automatic drain cocks for cylinders.

All valves, couplings, oilers, bells, &c., shall be of pattern approved by the Engineer Officer in charge.

Two steam gauges shall be furnished, one fourteen inches and one twelve inches diameter.

Boiler and pipe coverings.—The boilers, steam pipes, exhaust pipes, heaters and steam drum shall be covered with the best quality of magnesia covering and approved by the Engineer Officer in charge.

Steam capstans.—There shall be two steam capstans, each complete, with double cylinders, reversing engines, bed plate, crank and counter shafts, pawl bed, and all of the necessary gearing, boxes, &c. All of a pattern approved by the Engineer Officer in charge, and properly set up. The two cylinders each shall be five inches diameter by ten inches stroke, with common slide valves, set side by side with steam chests facing each other, about twenty-six inches between centres of cylinders, on upright cast-iron bed plates, in two pieces nine and one-half feet over all in length, with a one-inch by six inches cross plate at the top, and brackets at the bottom to support the crank shaft, and the plates bolted to five inches by twelve inches white pine, free of heart, clear and seasoned, and extending from bottom of hull to under side of roof line.

The crank shaft shall be of steel three and one-half inches diameter, about five feet nine inches long, with the cranks near the after end, a pinion seven inches diameter near the forward end and a counter balance wheel thirty inches diameter, weighing about three hundred pounds, between the cranks and pinion.

The counter shaft shall be of steel three and one-half inches diameter, about three feet six inches long, with a spur wheel on the after end about twenty-eight inches diameter gearing into the crank shaft pinion, and a bevelled pinion on the forward end gearing into the under side of the crown wheel on the spindle, but sliding loose on a key and held by a heavy collar with a set screw.

The crank shaft shall have four boxes, one at each end, one between cranks, and one between fly-wheel and forward pinion. The counter shaft with one box near each end, all extra heavy, five inches wide, well babbitted, each having jam nuts, and lubricating openings of ample size in each cover.

The spindle shall be of steel about five feet six inches long, five inches diameter from the pawl bed to under side of crown wheel, about twenty-four inches below the deck, and tapered to three and one-half inches diameter at the ends, extending forty-two inches above deck, and down through adjustable bronze boxes, flush with top of pawl bed, and through the crown wheel in the hold into a heavy cast-iron step, fastened with four bolts three-fourths inch diameter, and steel collar two inches by one-inch with three-fourths inch set screws fitted on the spindle, under the deck and under the crown wheel.

Pawl bed shall be of cast-iron one inch thick, twenty-eight inches diameter with three-fourths inch stops.

The gearings shall all be of steel castings and so arranged that the barrel will make one revolution for sixteen full strokes of the engines.

The barrel shall be double the top set forty-two inches above the deck, twenty inches outside diameter at the head, eighteen and one-half inches at the top whelp plate, and twenty-four and one-half inches outside the lower band and made of clear seasoned black locust.

The head shall be five inches thick, east with three-fourths inch half round overhanging bead at top, and with six four-inch square openings for capstan bars, and fastened to the spindle with three-fourths inch square key with a gib head. Top whelp plates shall be eighteen and one-half inches diameter, three inches thick, cast with six bevelled recesses three inches by four and one-half inches to receive the tops of whelps, and the plate secured to the head by one and one-fourth inch steel pins. Lower whelp plate shall be twenty-four and one-half inches diameter, four inches thick, and cast with six bevelled recesses three inches by three and one-half inches for bottom of whelps, and three iron bands to secure wood filling, one for the top three-eighths inch by two inches by seventeen and three-fourths inches inside diameter, one for the middle, one and one-half inches half round, nineteen and one-half inches inside diameter, and one for the bottom one-half inch by twenty-three and one-half inches inside diameter, the whole constructed in an approved manner.

Wheel.—The shaft shall be of steel sixty-five thousand pounds tensile strength, hexagonal in form with seven inches inscribed diameter and forged in one piece and annealed. Cranks shall be of steel of the same tensile strength as shaft, and of pattern approved by the Engineer Officer in charge. There shall be four flanges of steel castings cast with sockets and lugs for eleven wheel arms. The journal and quarter boxes shall be of phosphor-bronze, well babbitted. The pillow blocks shall be of best cast-iron of a pattern approved by the Engineer Officer in charge.

Wheel arms shall be two inches by four inches at sockets, and two inches by eight inches at ends. Circle braces two inches by five inches. Buckets in two widths, each fourteen inches by seventeen feet long and one and one-half inches thick. Battens six inches by one and one-half inches. Arms, braces, buckets and battens all of seasoned white oak free from heart and all defects.

Each flange shall have two iron circles three-sixteenths inch thick by four inches wide.

Wheel shall be balanced as required.

DECK HOUSE.

Material.—All of the lumber used in the construction shall be clear and thoroughly seasoned, dressed both sides and edges and of the sizes specified after having been dressed. The tongued and grooved lumber for the sides shall be beaded on both sides and for the roofs on one side.

Dimensions and arrangements.—The deck house shall be eighty-nine feet from forward end of pilot house to splash bulkhead, nine feet high to top of main clamps, twenty-four feet wide at bottom line at forward end and continue the same width to splash bulkhead, and to have a tumble of two and one-half inches on each side and a crown of four inches.

The lower deck arrangement shall be as follows :—Forecastle thirteen feet ; fire room ten feet ; boiler room thirty-eight feet ; deck room twelve feet ; and

engine room twenty-nine feet. The fire room, boiler room, deck room and engine room enclosed by bulkheads as shown.

Construction.—The main clamps of the deck house shall be one and one-half inches by ten inches white pine and extend the full length of sides. Skylight and pilot house clamps shall be one and one-eighth inches by eight inches white pine.

Main stanchions shall be of oak four inches by four inches at top and four inches by six inches at bottom, eleven on each side and spaced as shown, top shall extend ten inches above the roof and be worked as a timber head, the bottom shall be connected to deck plating with a gusset plate of five-sixteenths inch sheet steel, flanged to rivet to the deck, extending twelve inches in and twenty-four inches up on side of stanchions.

The corners of main stanchions that intersect gusset plates shall have a three-inch by three inch by one-fourth inch angle rivetted to gusset plate and extending up to the under side of the main clamp, and stanchions bolted to gusset plate with one-half inch screw bolts.

Each main stanchion to have a swinging fender of oak six inches by eight inches properly hung.

Carlines of deck house frame shall be one and one-eighth inches by five inches white pine, let in flush with top of clamps and flush with face of main stanchions, and all spaced twenty inches between centres with a crown to conform to main deck. Carlines for skylight and pilot house roof shall be one inch by four inches white pine, let in flush with tops of clamps and shall have a crown of two inches for the skylight roof and three and one-half inches for the pilot house roof between clamps.

Skylight shall be seventy-six feet long extending forward from splash bulkhead thirty inches high, and seven and one-half feet between clamps, spaced into thirteen sash on each side for twelve inches by sixteen inches lights of glass sash shall be one and one-eighth inches thick, hung at the top, and provided with hooks and buttons. Skylight shall be supported by ridge poles of four inches by six inches yellow pine, bolted to tie carlines of five-inch by three-inch by three-eighths inch angles, shaped to conform to crown of roof and rivetted to corner angles of main stanchions by means of one-fourth inch gusset plates.

The fire, boiler, deck and engine rooms shall be closed in on the sides and partitioned off with bulkheads as shown on the drawings, all constructed of seven-eighths inch white pine, matched with tongue and groove, beaded on one side and secret and double nailed at all bearings. The spaces between the main stanchions shall be filled with one-inch by three-inch white pine stanchions sixteen and one-half inches between centres, gained into a deck sill of three-inch by three-inch oak set one-inch above deck plating and connected to main stanchions. Batten doors shall be made in the forward bulkhead of engine room on each side hung with heavy strap hinges and sliding batten doors on each side of engine room along the cylinders and slides, secured with hooks and eyes. Two large sliding batten doors shall be made in the bulkheads alongside of boiler room on

each side hung with barn door hangers and located as shown. There shall be two batten doors in the cross bulkhead at aft end of pilot house, one on each side hung with heavy strap hinges. The bulkheads alongside of boiler room shall further have batten doors sixteen inches wide hung with heavy strap hinges five inches below the carlins the full length of the boiler room on each side.

The deck room shall have two doors with the lower parts paneled and the upper parts six lights of glass.

The splash bulkhead shall be of one inch white pine, matched with tongue and groove, secret and double nailed to two inch by four inch white pine stringers and to filling of false transom, and shall extend from top of skylight roof to under edge of false transom, and shall have two fantail doors.

Two coal bunkers three feet wide by fourteen feet long by six feet high, shall be built in the boiler room, one on each side of the boiler, located as shown.

Pilot House.—The pilot house shall be eleven feet wide by ten feet long, and seven feet high in the clear inside above the level of cabin roof, boxed in at forward end for pilot wheel ; corner stanchions four inches by four inches oak extending from deck to roof and secured to the deck plating in the same manner as main stanchions. Sides and front of pilot house shall be closed in with seven-eighths inch white pine, matched with tongue and groove, beaded one side for the lower part down to main deck and the upper part shall be framed for three sliding sash, on each side and rear, of four lights of glass seventeen inches by twenty-four inches. Sash shall be one and three-eighths inches thick, and slide on a table of oak, with oak parting strips between, at top and bottom, each sash to have rollers to slide on. The front of pilot house shall have folding sight shades, properly hung.

A sash door one and three-eighths inches thick, six feet high and upper part six lights of glass, shall be placed at the after port corner of house near the head of stairs leading down to the forecastle deck as shown.

Pilot Wheel.—The pilot wheel shall be nine feet in diameter over the spokes and hung with approved anti-friction bearings.

Roofs.—The roofs of pilot house, skylight and deck house, shall be laid with seven-eighths inch white pine, matched with tongue and groove, beaded one side, secret and double nailed to all bearings and covered with U. S. Standard twelve ounce canvas, twenty-nine inches wide, well lapped and well tacked on the edges with ten ounce tacks and all painted three coats of yellow ochre and white lead ground in boiled linseed oil (about four pounds of lead to the gallon) and sanded with good sharp sand of fine grain.

Roof projections shall be finished off with facing, nosing and waterway. Nosing and facing for skylight and pilot house shall be seven-eighths inch by four inches white pine. Facing for deck house roof shall be one inch by five inches oak, scarfed together with twenty-four inch scarfs. The nosing for deck house roof shall be four and one-half inches by seven-eighths inch oak and scarfed the same as the facing, and the waterway shall be of white pine seven-eighth inch by two and

one-half inches. The pilot house roof shall project twelve inches, skylight roof eight inches, and deck house roof shall be flush with main stanchions.

Spouts and Scuppers.—The spouts and scuppers shall be of No. 22 galvanized iron. There shall be two down spouts, two and one-half inches in diameter, one at each corner of after side of pilot house roof, leading down to main deck house roof; four on each side of skylight leading down to roof, of the same size. Deck house roof shall be supplied with six swinging scuppers, each three inches in diameter, on each side to throw overboard.

MISCELLANEOUS.

Equipment Engine Room.—The engine room shall be equipped with all of the foot boxes, lockers, vise benches, speaking tubes, bells and gongs required, all of approved patterns and designs. An alarm whistle for engine room and a whistle of approved pattern for the pilot house, shall be provided and set up.

There shall be furnished a tiller rope of five-eighths inch wire cable, properly hung with antifriction sheaves and fair leaders as may be approved.

A water closet shall be built in the engine room against splash bulkhead as shown, and furnished with a sixteen inch tube down through rake plating, well secured and the connection made thoroughly watertight.

Painting.—The hull, machinery, deck house, skylight, and pilot house shall be painted inside and out, four coats of paint of pure white lead and boiled linseed oil, in colours as may be selected, and the front and sides of pilot house and the sides of engine room and splash bulkhead be lettered as may be directed.

All of the work must be done in the most workmanlike manner.

ST. LOUIS, Mo.,
December 14th, 1898.

(Signed) THOS. H. HANDBURY,
Major, Corps of Engineers, U.S.A.

APPENDIX F.

LOG OF THE U. S. STEAMER *MISSISSIPPI*—INSPECTION TRIP OF THE COMMISSION FROM ST. LOUIS, MO., TO NEW ORLEANS, LA., DECEMBER 3RD TO DECEMBER 13TH, 1898.

Saturday, December 3rd, 1898.

ALL of the members of the Commission and the Secretary, together with Captain H. C. Newcomer, Corps of Engineers, Mr. E. F. Dawson, Executive Engineer, Public Works Department of Bombay Presidency, India, and U. S. Assistant Engineer F. B. Maltby, boarded the steamer *Mississippi* at St. Louis, Mo. (191 R.) at 10 A.M., December 3rd, 1898.

The steamer *Mississippi*, Grant Marsh, master, Anthony Burbach and J. W. Renfrow, pilots, left St. Louis at 11-5 A.M.

Passed Chester, Ill. (116 L.) at 5 P.M.

Reached Grand Tower, Ill. (85 L.) at 8 P.M. and took on 20 tons coal from Big Muddy Coal Co. Left at 9-30 P.M.

Gauge Readings: St. Louis, 4¼ F.
Chester, 3 F.
Grant Tower, 6 F.

		Above Cairo.	Feet.
Soundings:	Arsenal Island	(186)	10½
	Quarantine	(179)	8
	Merramec Island	(170)	8
	Sulphur Springs	(167)	9
	Harrisonville	(163)	8
	Crystal City	(159)	9
	Michaels Hollow	.....	7
	Danbys	(150)	7
	Ames Towhead	.....	7½
	Dickyfield	.....	9
	Cambria Hollow	.....	9½
	Ste. Genevieve Island	(131)	9½
	Foot of Ste. Genevieve Bend	(127)	8
	Mouth Okaw River	(125)	8
	Kaskaskia	(123)	12
	Crains Island	(112)	9
	Kirks	(110)	9
	Liberty Island	(105)	8½
	76 Towhead	(95)	8

Sunday, December 4th, 1898.

Passed Cape Girardeau, Mo. (54 R.) at 12-30 A.M. Landed at Burnhams Island (40) at 2 A.M. Weather stormy. Left at 6 A.M. Arrived at Cairo at 9-40 A.M. Took on 300 bushels of coal from Cairo City Coal Co. Left at 12 noon. Captain Winslow joined the boat at Cairo. Passed Belmont, Mo. (21 R.) at 1-30 P.M. Arrived at New Madrid, Mo. (71 R.) at 6 P.M. Left at 7-45 P.M. Arrived at Point Pleasant, Mo. (80 R.) at 8-30 P.M., where 700 bushels of coal were taken on board from steamer *Frisbie*. Left at 12 midnight. A delegation of citizens from New Madrid appeared before the Commission. Twenty-four hours' run, 200 miles.

Gauge Readings: Cape Girardeau, 7 F.
Cairo, 14¼ F.
Belmont, 13½ F.
New Madrid, 11 F.

		Above Cairo.	Feet.
Soundings:	Tower Island	(80)	9
	Crawfords	(76)	7½
	Tea Table	(71)	8
	Bainbridge	(66)	9
	Davidsons	(63)	9½
	Head of Devils Island	(61)	7½
	Foot of Jacket Pattern	(38)	9
	Philadelphia Point	(34)	5
	Buffalo Island	(31)	10½
	Brooks Point	(27)	9
	Orient Field	(24)	12
	Thompsons	(20)	10½
	Scudder Towhead	(18)	9
	Hurricane Field		9
	Eliza Point		8½
		Below Cairo.	Feet.
	Cairo Point	(3)	12
	Point Pleasant	(79)	13½

Monday, December 5th, 1898.

Returned to New Madrid, Mo. (171 R.), arriving at 1-15 A.M. Left at 7-30 A. M. Weather clear and cold. Arrived at the U. S. dredge *Epsilon* at 8-30 A.M. Left at 10 A.M. Passed Gayoso, Mo. (106 R.) at 11 A.M. The Commission inspected the revetment work along the river front of New Madrid, Mo. (71 R.). Mr. Mott and Davis, of Point Pleasant, Mo., appeared before the Commission. Landed at Caruthersville, Mo. (110 R.) at 11-30 A.M., where the Commission inspected the mattress work at this point. Twenty-four hours' run

105 miles. Left at 12-30 noon. Passed Cottonwood Point, Mo. (123 R.) at 2-30 P.M. Passed Fulton, Tenn. (175 L.) at 7 P.M. Arrived at West Memphis (232 R.) fleet at 12 midnight. Took on 520 bushels coal from barge No. 42. At 4-45 P.M. the Commission inspected the various works along Plum Point Reach.

Gauge Readings: Cottonwood Point, 9¼ F.
Fulton, 10 F.

		Below Cairo.	Feet.
Soundings:	Lazelles	(83) ...	12
	Cherokee	(90) ...	12
	Kate Aubry Towhead	... ...	13½
	Island No. 34	(179) ...	13½
	Presidents Island	(233) ...	9

Tuesday, December 6th, 1898.

Left the Government fleet, West Memphis, Ark. (232 R.) at 6 A.M. Landed at Mound City Ferry at 7 A.M. The Commission inspected the work along Hopefield Bend and then landed at Memphis, Tenn. (230 L.) where the revetment work was inspected. Mr. H. N. Pharr, Chief Engineer of the Lower St. Francis Levee District, appeared before the Commission. Judge Taylor left the boat at Memphis, Captain Jervey, Corps of Engineers, Major Richardson, Chief State Engineer of Louisiana, and Mr. C. H. Purvis, Chief Engineer, Cotton Belt Levee District, joined the boat at Memphis. Left Memphis at 10 A.M., landed and inspected the Government fleet at West Memphis. Twenty-four hours' run, 125 miles. Passed Mhoons Landing, Miss. (277 L.) at 3 P.M. Arrived at Helena, Ark. (306 R) at 6 P.M., where the Commission inspected the work along the river front. Took on 250 bushels coal from J. A. Tappan. Left at 8 P.M. Passed Sunflower Landing, Miss. (353 L.) at 11-30 P.M. No Bulletin. Captain Winslow and Mr. Purvis left the boat at Laconia, Ark. (374 R).

Gauge readings: Memphis, 8¼ F.
Mhoons Landing, 7½ F.
Helena, 14 F.

Wednesday, December 7th, 1898.

Arrived at Arkansas City, Ark. (438 R.) at 6 A.M. Judge Pindall, Mr. Lambkin, and Mr. Parker, President, Tensas Basin Levee Board, came aboard and addressed the Commission. Took on 185 bushels coal from the Pittsburg Coal Co. Left at 8 A.M. Arrived at Greenville, Miss. (478 L.) at 11 A.M. Left at 12-15 P.M. Twenty-four hours' run, 248 miles. Passed Lake Providence, La. (542 R) at 5-15 P.M. Arrived at Vicksburg, Miss. (599 L.) at 9-30 P.M. Arrived at Delta Point at 10-30 P.M. Took on 875 bushels coal from Peatress and Cameron Coal Co. The Commission inspected the work along Ashbrook Neck (446 L.), along the river front of Greenville, Miss., the

works along Lake Providence Reach, and the caving at the head of Lake Providence revetment. Mr. West, Chief Engineer, Mississippi Levee Board, and Maj. Starling, U. S. Assistant Engineer, joined the boat at Greenville, Miss.

Gauge Readings: Arkansas City, 16 F.
Greenville, 13¾ F.
Lake Providence, 12½ F.

Thursday, December 8, 1898.

Returned to Vicksburg, Miss., at 8 A.M. Capt. Newcomer left the boat at this point. Left Vicksburg, Miss., at 10-30 A.M. Twenty-four hours' run, 118 miles. Passed St. Joseph, La. (648 R.) at 3 P.M. Took on 312½ bushels coal from Pittsburg Coal Co. Maj. J. H. Willard, Corps of Engineers, came on board. Mr. Ransdell appeared before the Commission. The Commission inspected the work of revetment at Delta Point, the caving which had occurred above this work and the site of proposed work. At 3-30 A.M., the Commission landed and inspected the caving bank at Kemps Bend and the new loop levée under course of construction. Arrived at Natchez, Miss. (700 L.) at 6-30 P.M. Mr. H. S. Douglas, U. S. Assistant Engineer, joined the boat at Natchez, Miss.

Gauge Readings: Vicksburg, 16 F.
St. Joseph, 12¼ F.
Natchez, 17½ F.

Friday, December 9, 1898.

Left Natchez, Miss., at 6 A.M. Raining and cold. Proceeded to Giles Bend (689) and inspected the caving bank and spur dikes, returning to Natchez, Miss., at 10 A.M. Mr. Douglas left the boat. Passed Hutchins Landing, Miss. (716 L.) at 11 A.M. Twenty-four hours' run, 105 miles. Passed Fort Adams, Miss., at 2-15 P.M. Raining and freezing. Entered the mouth of Red River at 3 P.M. and proceeded to Simmsport, La., where the sill dams placed across the Atchafalaya were inspected by the Commission. Mr. Wooley, U. S. Assistant Engineer, came aboard and appeared before the Commission. Returned to the *Mississippi* and landed at Red River Landing, La. (765 R.) at 6 P.M. Left at 7 P.M. Arrived at Baton Rouge, La. (833 L.) at 12 midnight.

Gauge Readings: Red River Landing, 17½ F.
Barbres Landing, 17 F.
Baton Rouge, 7¼ F.

Saturday, December 10, 1898.

Took on 500 bushels coal from Wood-Bodley Coal Co. Left Baton Rouge, La., at 6-45 A.M. The Commission inspected the caving bank just above Plaquemine, La. (854 R.) and then landed at 8-30 A.M. and inspected the work being done on the lock leading into Bayou Plaquemine. Left at 9 A.M. Passed

Woodstock Landing, La. (878 R.) at 11 A.M. Twenty-four hours' run, 92 miles. Passed College Point, La. (904 L.) at 1 P.M. Landed at Judge Ross' Plantation, 25 miles above New Orleans. Passed Carrollton, La. (957 L.) at 6 P.M. Arrived at New Orleans, La. (964 L.) at 7-30 P.M.

Gauge Readings : Plaquemine, 7½ F.
College Point, 5½ S.
Carrollton, 5½ F.

Sunday, December 11, 1898.

The Commission left the landing at New Orleans at 9-45 A.M., and visited the various works in the New Orleans Harbour, returning to the landing at 2 P.M. Took on 750 bushels coal from W. H. Browns' Sons. Col. Gillespie, Col. Stickney, Maj. Handbury, Maj. Harrod, and Capt. Jervey left the boat at 7 P.M.

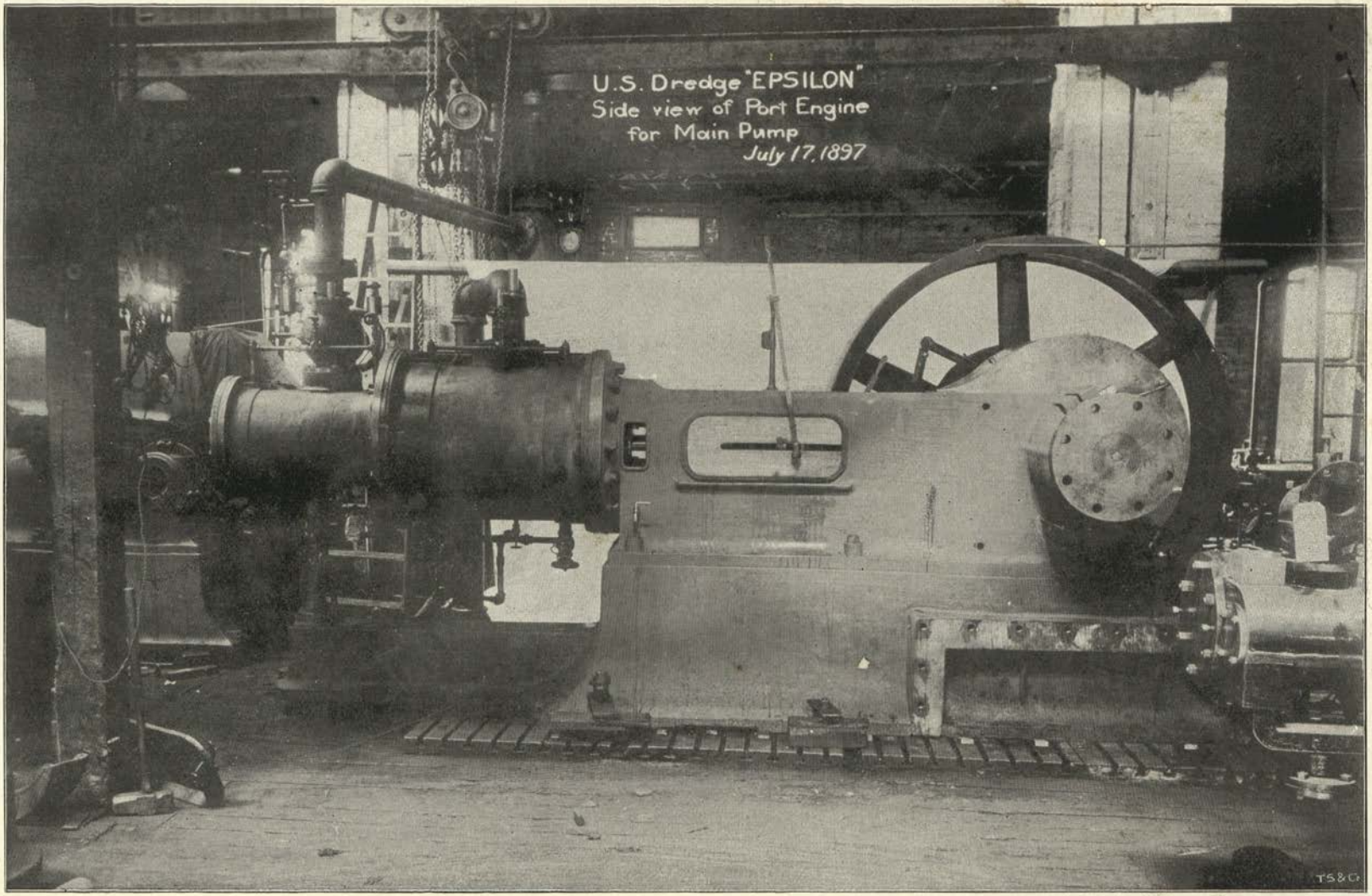
Monday, December 12, 1898.

Left the landing at New Orleans, La., at 5 A.M., and proceeded to the Jetties, landing at Port Eads, La. (1072) at 2-30 P.M. Left at 3 P.M., and landed at Magnolia Plantation (1012 R.) at 9-30 P.M. Fog.

Tuesday, December 13, 1898.

Left Magnolia Plantation at 6 A.M. and landed at New Orleans, La., at 11-30 A.M. Mr. Marindin, Mr. Ockerson, Mr. Dawson, Maj. Starling and the Secretary left the boat.

U. S. Steamer MISSISSIPPI. Dec. 1898.



U. S. Dredge EPSILON. Side view of Port Engine for Main Pump. July 17, 1897.

00063807

Digitized with financial assistance from the
Observer Research Foundation
on 25 April, 2019